MINERALIZATION, MINERAL POTENTIAL AND METALLOGENESIS OF THE CORDILLERA REAL OF ECUADOR

British Geological Survey

Keyworth
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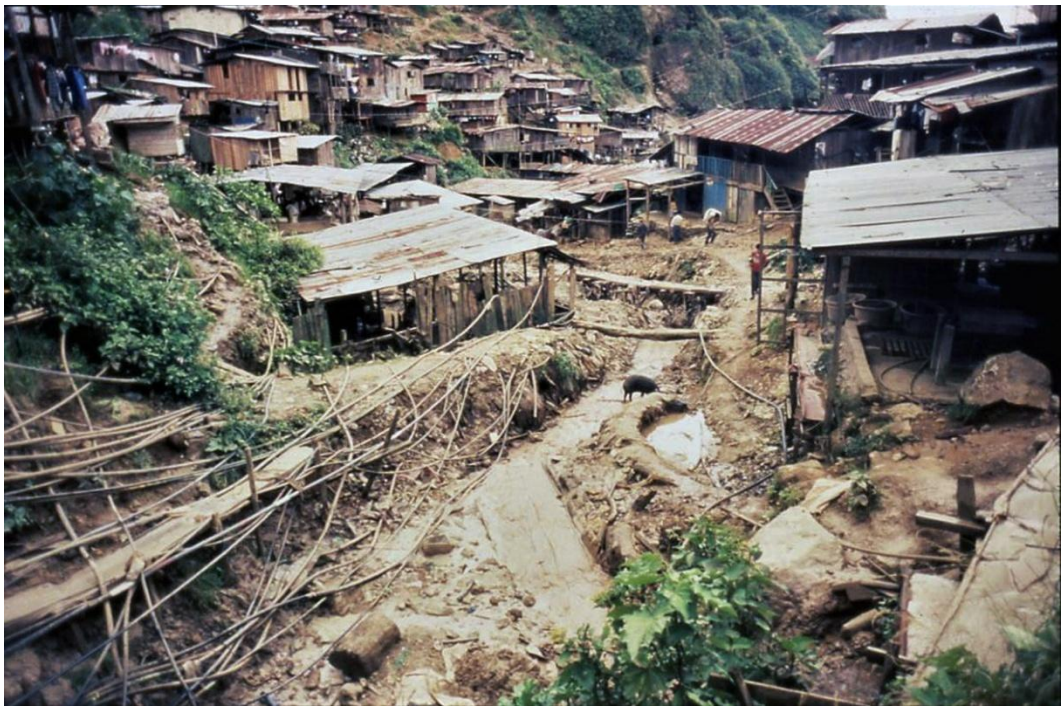
PATRI MATRIQUE



Nambija mine in 1988 and its main 'street' polluted with mercury and arsenic where pigs and children wade

Gold fever

"So what do you do all day up in the mountains?"
"Surveying the rocks," say I.
Faces then pucker with misunderstandings:
'Looking for gold then," I sigh.

In Latin America nobody goes
Up into the hills for fun.
It's always for treasure or nuggets of gold:
Shining, sparkling, in the Sun.

They dream of their gold in those stories of old
Passed down from father to son.
They know where it lies: in those hills further back:
The end of the rainbow's run.

Just look at Nambija: a mountain of gold:
A triumph of lust and greed:
There's squalor and poison, mayhem and murder:
Dante's Inferno indeed.

Yet a perverse seduction's haunting the place,
If you overcome the smell.
They're dicing each day for death or tomorrow:
It's drama, it's life, it's Hell.

It came with the Spanish, this fever for gold:
Just a missionary vice.
Destroying the Incas who worshipped the Sun
For something without a price.

No farmers were they, Pizarro and Cortez,
To work the soil and grow old.
But they still rule their lands in the name of Christ
Upon their altars of gold.

Martin Litherland
Inca Treasure
Poems from the Andes of Ecuador

Family group washing gold in the Sardinas area of the Río Jatunyacu

View to Peggy mine with mineralised, sheared granite in the mine area

Overseas Development Administration,
Foreign and Commonwealth Office,
United Kingdom of Great Britain
and Northern Ireland

Ministerio de Energía y Minas,
República del Ecuador

MINERALIZATION, MINERAL POTENTIAL AND METALLOGENESIS OF THE CORDILLERA REAL OF ECUADOR

Final report of the results of the
Economic Geology Survey of the
Cordillera Real Geological Research Project (1991-1993)
CODIGEM – Misión Británica, Quito

by

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Stalyn Paucar

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Reference

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PREFACE

This report summarises the results of a two-year study (1991-1993) of the economic geology and mineral potential of the eastern Cordillera (Real) of Ecuador. This study is part of the Cordillera Real Geological Project (1986-1993), a bilateral technical cooperation project between the Government of Ecuador (Ministry of Energy and Mines) and the Government of the United Kingdom of Great Britain and Northern Ireland (Foreign and Commonwealth Office/Overseas Development Administration).

Field and office work was conducted by Dr. Richard A. Jemielita (BGS/ODA), and Ing. Johnson Bolaños (INEMIN/CODIGEM), as well as occasional contributions by other INEMIN/CODIGEM staff. All other contributions to this report are referenced as appropriate.

The study area comprises the eastern Cordillera (Real) of Ecuador (Figure 1), a 650 km long by about 60 km wide segment of the Andes. Elevations range from 1000 m in the east (Oriente) to nearly 6000 m on the summits of (recently) active volcanoes. Areas of economic interest seldom exceed 4500 m.

Climate and vegetation vary from temperate grassland on the western slopes, becoming cold, cloudy, wet moorland (páramo) at higher altitudes. The eastern slopes are similarly cold, wet and cloudy, with thick cloud forest almost reaching the watershed. At lower altitudes the eastern slopes become more tropical in climate and vegetation.

Studies have concentrated on the basement metamorphic and plutonic lithologies of the main mass of the Cordillera Real, but have also included the flanking young volcanic lithologies of the inter-Andean graben to the west; and mostly sedimentary rocks of the sub-Andean foothills to the east. Limited studies were also made within the Zamora batholith area of southeast Ecuador because of the current and potential future economic importance of this area.

The study area is generally remote and inaccessible with only four roads suitable for motor vehicles crossing the Cordillera Real. Access was normally made by 4WD vehicle and a combination of mule/horseback, canoe, or on foot. Guides and porters (usually native indians) are obtainable from the local mountain and rainforest communities.

Good 1:50000 scale topographic maps are available (Appendix A) for much of the Cordillera Real and similar scale, but less detailed (Census) maps cover some areas. A few very detailed 1:25000 scale maps are also available. Much of the Cordillera Real is covered by reasonably good quality aerial photographs (1:40000 to 1:60000 scale). Landsat and SAAR images can be obtained.

SUMMARY

The Cordillera Real of Ecuador comprises an elongated mosaic of metamorphic-batholithic intrusive divisions, some of which are interpreted as accreted terranes. Regional geological mapping has divided this largely inaccessible and unexplored region into five, informal, Andean-trending lithotectonic divisions. An appraisal of their metallogenesis and mineral potential has been made by considering known metallogenic - lithotectonic associations supported by "grass-roots" exploration.

From west to east, basement geology comprises the Guamote division of flysch sediments, bounded eastwards by the ophiolitic Peltetec fault; the Alao division, a mid-Jurassic oceanic island arc terrane bounded eastwards by the Baños fault; the Loja division, a Triassic S-type biotite (± muscovite ± garnet) granite batholith with flanking semi-pelitic lithologies; and east again, the Salado division of plutonic and island arc lithologies; followed by the Zamora division of continental plutonic and volcanic rocks. The metamorphic-plutonic basement is intruded, in places, by late Cretaceous mafic-ultramafic plugs and Tertiary diorite-granodiorite and porphyritic rhyolite-dacite plutons. The Cordillera Real is flanked to the west by Tertiary andesitic-rhyolitic volcanic and volcaniclastic rocks of the inter-Andean graben and, in places, by Miocene basin sediments. To the east, Cretaceous and younger sediments of the sub-Andean zone are in tectonic or unconformable contact with the basement lithologies.

The following types of mineralization have been identified in the Cordillera Real and adjacent areas:

Volcanogenic Massive Sulphides: At least two examples of VMS mineralization have been identified within meta-volcanic lithologies of the Alao-Paute subdivision (pyrite-Au deposit), and the Upano subdivision (polymetallic deposit).

Gold Skarns: Gold is currently being extracted from skarn deposits hosted within volcano-sedimentary roof pendants (Isimanchi subdivision) within the Jurassic Zamora granodiorite-diorite batholith (Abitagua subdivision).

Granodiorite Intrusion-Related Mineralization: Some Tertiary granodiorite plutons and their (hydro-) thermal aureoles host disseminated sulphide and vein quartz-sulphide mineralization.

Porphyry-Related Mineralization: Polymetallic, disseminated, vein and intrusive breccia mineralization occurs along the west flank of the Cordillera Real, especially along the Las Aradas-Baños fault.

Epithermal Ag-Au mineralization: Working and historical silver mines occur, together with epithermal vein, disseminated and breccia prospects which carry anomalous Ag, Au and other metals, in Miocene to Recent, andesitic to rhyolitic volcanic, volcaniclastic and intrusive lithologies of the inter-Andean graben, especially where these rocks lap onto the western flank of the Cordillera Real, close to the Las Aradas-Baños fault.

Shear Zone-Hosted Mesothermal Quartz Veins: Mesothermal quartz veins occur widely within the sheared metamorphic-plutonic basement lithologies of the Cordillera Real but are known to be auriferous at a few localities only. Mineralization of this type probably sourced much of the alluvial gold in palaeoplacer and alluvial deposits located along the flanks of the Cordillera.

Other types of primary mineralization in the Cordillera Real include intrusion-related molybdenum and polymetallic occurrences, mafic-ultramafic intrusion-related Platinum Group Metals, and alluvial tin and tungsten occurrences related to an S-type granite.

Secondary mineralization is represented by potentially huge palaeoplacer and alluvial gold deposits in Cretaceous and Tertiary sedimentary formations which occur mostly on the flanks of the Cordillera Real, especially to the east in the sub-Andean zone and the Oriente.

The widespread occurrence of alluvial gold in rivers draining the Cordillera Real has been known since Spanish colonial times but none of the other types of mineralization described above have previously been widely recognized. These discoveries indicate the tremendous economic mineral potential of this region, one of the least known and least exploited segments of the Andes.

1. GEOLOGY AND MINERALIZATION OF THE CORDILLERA REAL OF ECUADOR

1.1 Previous geological studies

The general geology of Ecuador was described in a classic study by Wolf (1892), including the first published geological map of the country. This work has been followed more recently by various books, memoirs and maps (Sauer, 1965; SNGM, 1969; Kennerley, 1980; Baldock, 1982). A new (1:1 million scale) geological map of Ecuador is in preparation (Litherland et al., in prep).

The geology of the eastern Cordillera (Real) of Ecuador was previously little studied, but since 1986 the metamorphic- plutonic basement of the area has been the subject of more detailed geological examination (Aspden et al., in press; Aspden and Ivimey-Cook, in press; Aspden et al., 1993; Aspden and Litherland, 1992; Litherland and Aspden, 1992). Much useful geological information is also contained in the Cordillera Real Geological Research Project annual reports and accompanying maps (Aspden, 1990; Litherland, 1987, 1988, 1989), and summary report (Litherland et al., 1990).

Previous studies of the economic geology and mineral potential of the Cordillera Real have also been rather limited in scope, and usually restricted to more general publications dealing with the entire country, or private mining company reports.

Navarro (1986) has reviewed documentary evidence pertaining to mining in Ecuador from early colonial times to the 20th century. Villavicencio (1858) made brief descriptions of alluvial gold deposits in rivers draining the Cordillera Real and other parts of Ecuador. Wolf (1892), in his book on the geography and geology of Ecuador, gives detailed accounts of mines in the country and describes selected alluvial gold areas in the Cordillera Real, accompanied by analyses of the gold. Other reviews of the economic geology of Ecuador, including information on the Cordillera Real, have been published occasionally by visiting geologists (Isschot, 1901; Holloway, 1932; Stoll, 1962). Other publications are listed in the annotated bibliography of Ecuadorian geology (Bristow, 1981).

Some economic geology information for the Cordillera Real is included in the metallogenic and mineral index maps of Ecuador (Goossens, 1969; Paladines, 1980, and memoir), and general reviews (Goossens, 1972a, b; Paladines, 1989). The auriferous rivers of the Cordillera Real are shown on the unpublished (1:1 million scale) map of the gold potential of Ecuador (Pillajo and Báez, 1983), but this map is not widely available. Pillajo (1982) also discusses the origin of alluvial gold in Ecuador. A new (1:1 million scale) metallogenic-tectonic map of Ecuador is in preparation (Litherland et al., in prep).

The first studies dealing strictly with the economic geology of the Cordillera Real of Ecuador have only recently been published (Litherland et al., 1990; Jemielita et al., 1992; Jemielita and Bolaños, 1992), and are superseded by the present report.

Other more restricted publications dealing with mines, prospects and mineral potential in the region are detailed in the text and references of this report.

1.2 Regional geological setting

The following description is based upon the work of Aspden et al. (in press), Aspden and Ivimey-Cook (in press), Aspden et al. (1992), Aspden and Litherland (1992), Litherland and Aspden (1992), and references therein.

The Andean Mountain chain in Ecuador comprises two distinct Cordilleras and forms the southern segment of the north-northeast trending Northern Andes (Gansser, 1973).

The coastal plain and Western Cordillera are thought to be underlain by a basement of allochthonous Cretaceous oceanic crust which was accreted to the South American continent along the line of the Calacalí-Pallatanga-Palenque fault (Figure 1), during latest Cretaceous-early Tertiary time.

The Western Cordillera is separated from the Cordillera Real by the narrow inter-Andean graben (Figure 1), a more or less continuous topographic depression, largely covered by Plio- Pleistocene volcanic deposits and bounded by the Calacalí-Pallatanga-Palenque fault in the west and the Peltetec fault in the east (Figure 1). These two faults may represent crustal sutures bounding an allochthonous (Chaucha-Arenillas) terrane basement to the inter-Andean graben.

South of 3°S, the Western Cordillera and inter-Andean graben give way to the east-west-striking, allochthonous, metamorphic lithologies of the El Oro Province of southwest Ecuador.

The Cordillera Real continues south into Peru, its western margin marked by the Las Aradas fault. The northern extension of the Las Aradas fault is the Baños fault, a regional structural feature of possible metallogenic importance.

The eastern margin of the Cordillera Real is characterized by a series of westerly-dipping, relatively high-angle thrusts, the Cosanga, Méndez and Palanda faults (Figure 1), that separate Cordilleran metamorphic lithologies from, essentially, unmetamorphosed Cretaceous sedimentary rocks and a regional scale belt of undeformed Jurassic plutonic and volcanic lithologies in the sub-Andean zone (Figures 1 and 2).

1.3 Geology of the Cordillera Real

The following description is a summary of recently published and unpublished material dealing with the geology and geological history of the Cordillera Real of Ecuador (Aspden et al., in press; Aspden and Ivimey-Cook, in press; Aspden et al., 1992; Aspden and Litherland, 1992; Litherland and Aspden, 1992). For further geological information the reader is referred to these works and references therein.

Within the Cordillera Real, five main lithotectonic divisions are recognized; the Guamote, Alao, Loja, Salado and Zamora divisions. The divisions have been further subdivided as described below and summarised in Table 1. The distribution of the divisions and sub-divisions is shown in Figure 2.

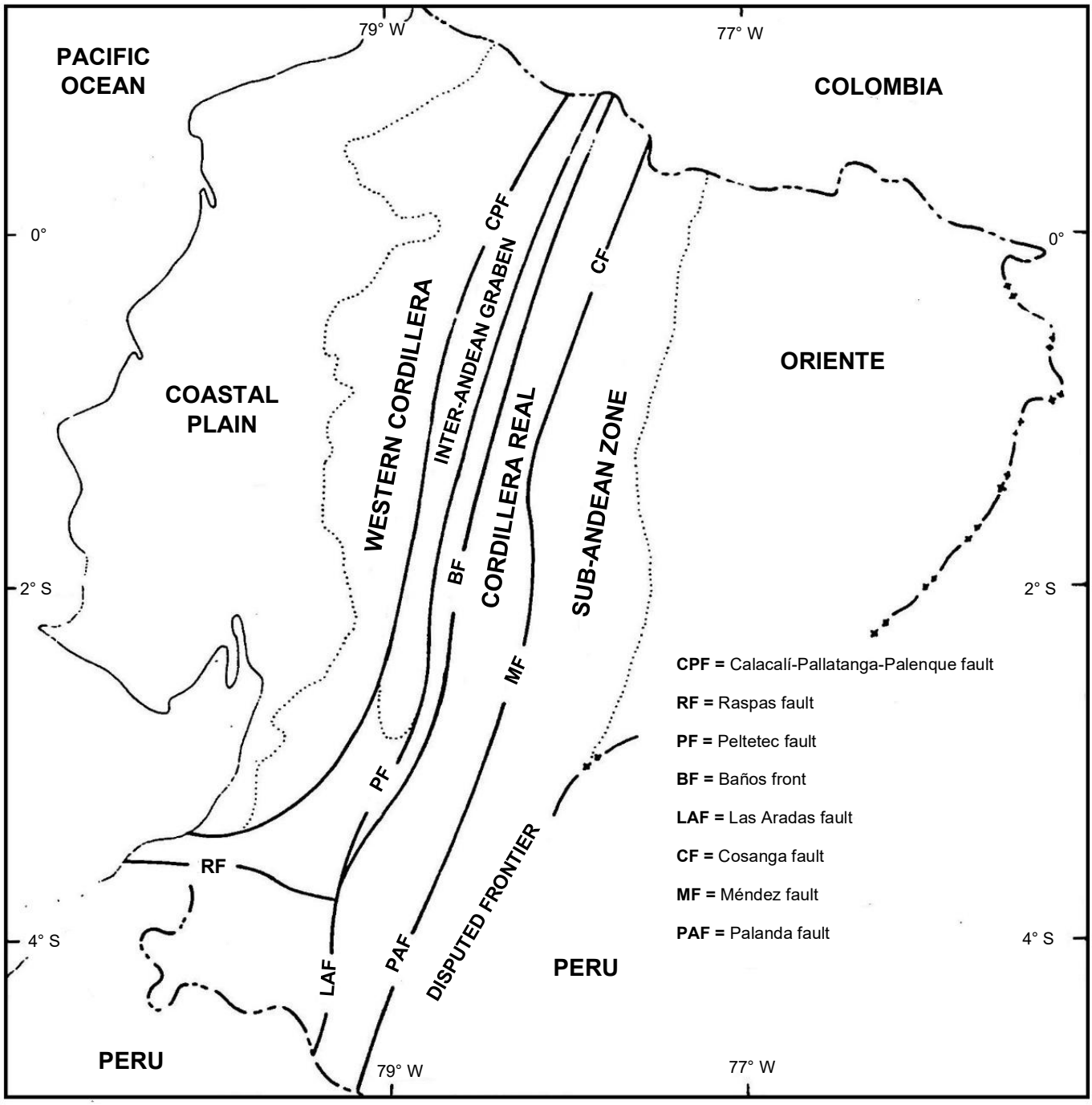

Figure 1. Principal faults and geomorphological features of Ecuador

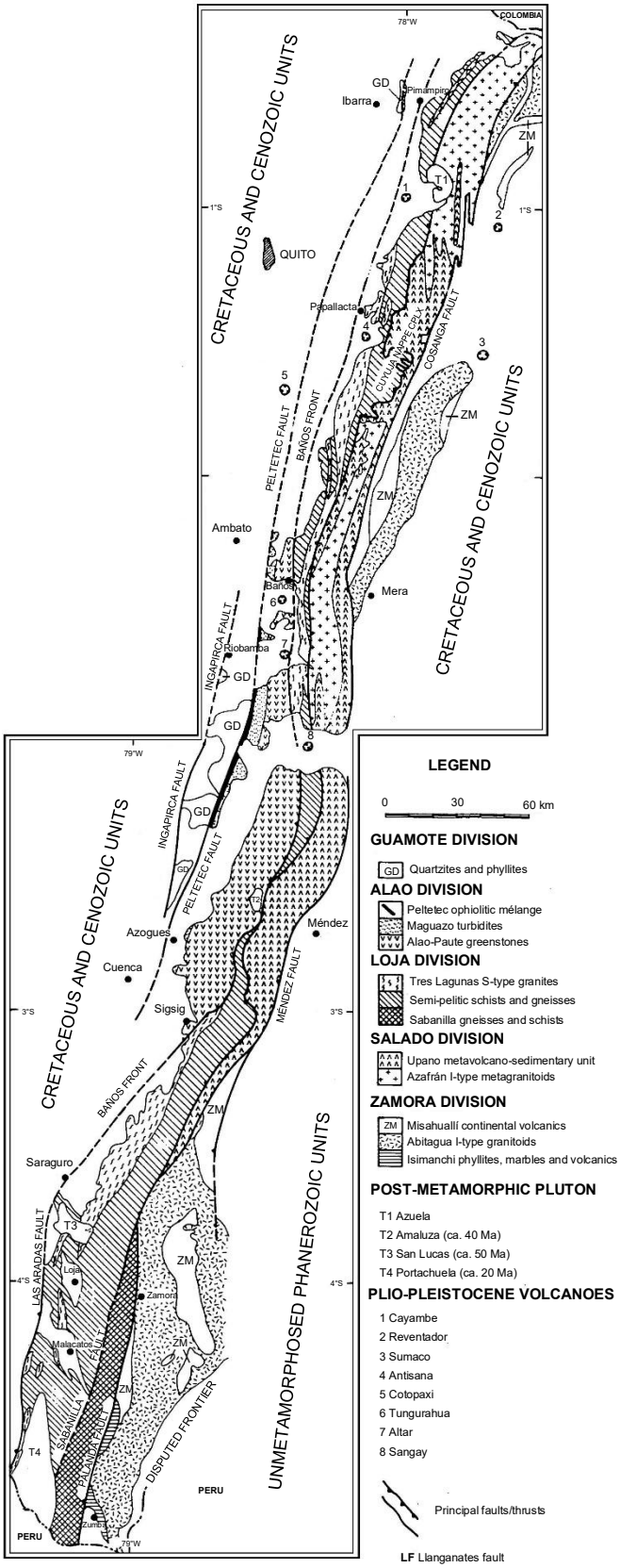

Figure 2. Simplified geological maps of the pre-Cretaceous rocks of the Cordillera Real and sub-Andean zone

The Guamote division outcrops along the western flank of the Cordillera Real and comprises a continentally-derived sequence of orthoquartzites, intercalated with low grade phyllites or slates. The Guamote division is bounded by the Ingapirca fault in the west and the Peltetec fault in the east. A lower Jurassic ammonite (Aspden and Litherland, 1992) provides a likely age for the Guamote division.

The Alao division also outcrops along the western slopes of the Cordillera Real, east of the Guamote division from which it is separated by the ophiolitic Peltetec fault. In the east, the Alao division is bounded by the Baños fault. The Alao division comprises three subdivisions:

In the west, the Peltetec subdivision comprises a narrow (<2 km) sequence of cherts, phyllites, spillitic basalts, dolerites, and minor lenses of Tres Lagunas type (Loja division) granite. The Peltetec subdivision is interpreted as an ophiolitic sequence.

To the east the Peltetec subdivision gives way across a tectonic contact to the Maguazo subdivision, dominantly comprising turbidites, in places rich in volcanic clasts, and andesitic greenstones. Green, metamorphosed tuffs, carbonaceous slates, minor amounts of marbles, orthoquartzites and cherts are also present.

Further east again, and in partially faulted contact with the Maguazo subdivision, the extensively exposed Alao-Paute subdivision outcrops. Alao-Paute subdivision lithologies are dominated by andesitic greenstones and greenschists, but some metasedimentary rocks are also present. Mineralogy usually reflects greenschist facies metamorphism. Fossil evidence suggests an age of 156 to 169 Ma (Callovian and Oxfordian stages; Middle/Late Jurassic) for the Maguazo subdivision of the Alao division (Aspden and Ivimey-Cook, in press).

The Loja division outcrops along the spine of the Cordillera Real, separated from the Alao division to the west by the Baños fault. In the east, the Loja division is in tectonic contact with, and overlies, the Salado division north of ca. 4°S, and further south it is thrust over the Zamora division along the west-dipping Palanda fault. North of Baños, the Llanganates fault separates the Loja and Salado divisions.

The Loja division can be separated into the meta- (S-type) granitoid Tres Lagunas subdivision (Aspden et al., in press), and migmatitic Sabanilla, subdivision, and a variety of lithologies comprising variably metamorphosed semipelitic rocks of the Chigüinda and Agoyán subdivisions. Loja division lithologies are normally characterised by steeply west- to vertical-dipping, Andean-trending schistosity, but narrow belts of flat tectonic foliation occur e.g. in the Cuyuja nappe complex. Loja division lithologies are often cut by Andean-trending shear zones, and S-C type mylonites have been identified in places. The Tres Lagunas granite has been dated at 227.6 ± 3.2 Ma by U-Pb zircon geochronology (Noble, 1992, pers comm.) and, together with Rb-Sr “errorchron” ages obtained for orthogneisses from the Sabanilla subdivision, indicates a Triassic age for magmatism and, probably, peak metamorphism of the Loja division (Aspden et al., 1993).

The Salado division is in tectonic contact with, and partially overlain by the Loja division but, south of 3° S, it is tectonically, and possibly stratigraphically, eliminated. The Salado division can be subdivided into the plutonic Azafrán and the volcano-sedimentary Upano subdivisions.

Table 1. Summary of the pre-Cretaceous geology of the Cordillera Real and sub-Andean zone

Division (West to East)	**GUAMOTE**		**ALAO**		**LOJA**		**SALADO**		**ZAMORA**
Subdivision/ Lithologies	Dark and pale orthoquartzites with slate/shale bands	**PELTETEC FAULT**	**Peltetec:** Dismembered ophiolite **Maguazo:** Turbidites **Alao-Paute:** Andesitic greenstones, tuffs and sediments	**BAÑOS FRONT**	**Tres Lagunas:** Biotite (garnet) granite and orthogneiss **Sabanilla:** Ortho- and paragneiss, associated with semipelitic phyllites, schists and paragneisses	**LLANGANATES FAULT**	**Azafrán:** Calc-alkaline batholith chain (diorite/granodiorite) **Upano:** Andesitic, greenstones, tuffs, black phyllites, greywackes and minor marbles	**COSANGA-MÉNDEZ FAULT**	**Abitagua:** Calc-alkaline batholite chain **Misahuallí:** Andesites, dacites, basalts and agglomerates **Isimanchi:** Marbles and volcano-sedimentary rocks
Tectono-metamorphic state	Very low-grade rocks overthrust W		Low-grade rocks, steep fabrics, upright folds		Low- to medium-grade rocks thrust E with imbrications		Low-grade rocks thrust E with imbrications. High-level skarnfield and serpentinite klippes		Essentially undeformed and unmetamorphosed
Age	?Upper Jurassic		Upper Jurassic (Oxfordian-Callovian)		?Triassic plutons in ?Palaeozoic sediments		Jurassic with possible pre-Jurassic elements		Isimanchi: Triassic Igneous rocks: Jurassic
Interpretation	Continental sediments/clastic wedge		Ocean floor, forearc and volcanic arc or marginal basin		S-type granites in continentally-derived sediments		I-type plutons in volcano-sedimentary sequence		Continental I-type plutonic-volcanic arc

The Azafrán subdivision comprises a batholithic chain which can be traced for almost 300 km from the Colombian border to ca. 2° S. Compositions of the intrusives range from gabbro, hornblendite and diorite to granodiorite and tonalite, and the plutons are variably deformed. A K-Ar age of 175 Ma has been obtained for a diorite from the Azafrán suite and is considered to be a reliable age for the subdivision (Aspden et al., 1993).

The Upano subdivision is a mixed volcano-sedimentary sequence including metamorphosed andesites, tuffs and agglomerates, greywackes, marbles, impure quartzites and black phyllites. These lithologies are variably deformed, and usually of greenschist facies grade (occasionally amphibolite facies). To the north of Baños, a series of high-altitude outliers (klippen) of skarn outcrop discontinuously along the spine of the Cordillera Real for about 150 km. The skarns lie between the Llanganates and Cosanga faults. The Upano subdivision is considered to be Middle- to Late-Jurassic in age.

The Zamora division outcrops to the east of the Cordillera Real sensu stricto, and principally comprises the plutonic Abitagua subdivision and the volcanic Misahuallí subdivision. The poorly known Isimanchi subdivision occurs in the southeastern part of the Cordillera Real. The Zamora division is separated from Salado division lithologies along the Cosanga, Méndez and Palanda faults (Figure 2). Zamora division lithologies are thought to be contemporaneous with the Salado division but the Misahuallí volcanics are mainly continental.

The Abitagua subdivision comprises the essentially undeformed calc-alkaline Zamora, Abitagua and Rosa Florida batholiths. K-Ar and Rb-Sr ages for Abitagua subdivision lithologies range from about 150 to 190 Ma (Aspden et al., 1993).

The Misahuallí subdivision consists of green and purple tuffs, lavas and agglomerates, sometimes containing sedimentary units. These lithologies are sometimes deformed and their age is not well established.

The Isimanchi subdivision comprises metamorphosed, immature, volcano-sedimentary phyllites, siltstones, tuffs and marbles, rich in volcanic debris. These rocks occur in the southeast of the Cordillera Real and comprise roof pendants in the Zamora batholith where they are host rocks to important gold-skarn deposits. Fossil evidence suggests a late Middle- to Late- Triassic age for the Isimanchi subdivision (Aspden and Ivimey-Cook, in press).

Basement lithologies of the Cordillera Real are cut, in places, by late Cretaceous granodiorite plutons and mafic- ultramafic plugs, and Middle- to Late-Tertiary granodiorite plutons, and dacite-rhyolite minor intrusions.

On the west flank of the Cordillera Real, volcanic and volcaniclastic lithologies of the inter-Andean graben, ranging in age from Miocene to Recent, are in fault contact, and partially overlap, basement metamorphic and plutonic lithologies (Figure 2).

In the sub-Andean zone of the Oriente, Cretaceous (Hollín and Napo Formations) and younger sedimentary units are exposed in the folded and thrust faulted Napo and Cutucú (anticlinal) uplifts. In the uppermost Cretaceous and later times, Andean uplift of the Cordillera Real resulted in the direction of sedimentary input into the Amazon basin changing from east to west (Baldock, 1982). This change had important implications for the generation of auriferous alluvial deposits.

A schematic section across the Cordillera Real is shown in Figure 3, together with a possible collision model to account for the disposition of the individual lithotectonic divisions.

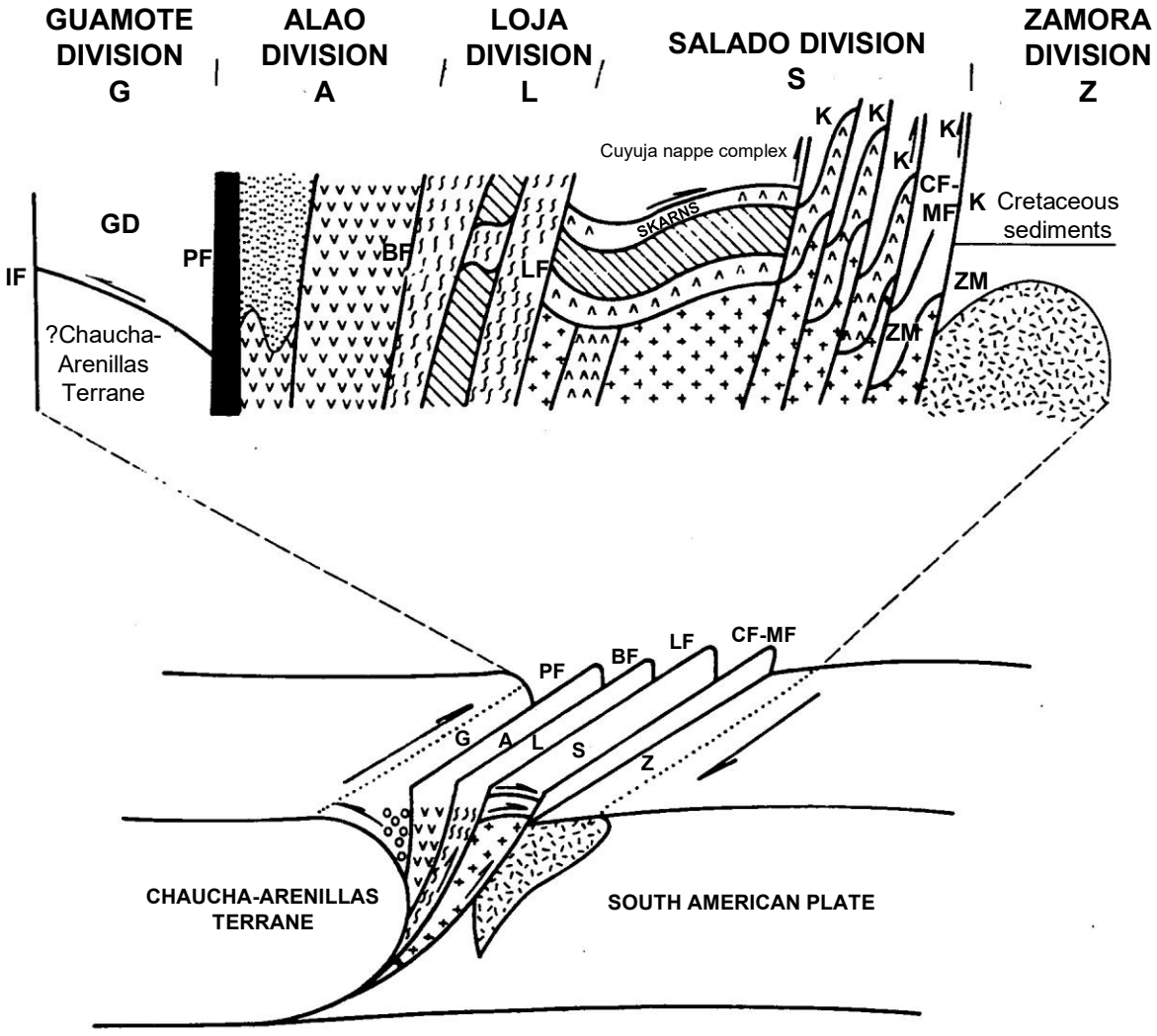

Figure 3. Schematic section across the Cordillera Real (see Figure 2 for stratigraphic details) and possible collision model to account for the disposition of the individual lithotectonic divisions. IF = Ingapirca fault, PF = Peltetec fault, BF = Baños front, LF = Llanganates fault, CF-MF = Cosanga-Méndez fault

1.4. History of Mining in Ecuador

Prior to Spanish colonization of Ecuador, the precious metals gold, silver and platinum were mined and worked by the indigenous people to produce jewellery and artifacts. Mining concentrated on gold and platinum-bearing alluvial deposits and silver may have been obtained from argentiferous veins.

During early Spanish colonial incursions, marked by the treacherous kidnapping and murder of the Inca King Atahualpa, gold and other precious artefacts were collected by the invaders. The ransom of Atahualpa in gold artefacts is said to have filled two rooms and weighed about 7.35 tonnes (Cuadra and Dunkerley, 1991). A recurring legacy of this era has been the periodic search for the remains of Atahualpa's ransom, rumoured to have been concealed by his general Rumiñahui at various localities, notably in the inaccessible Llanganates range in the Cordillera Real.

Spanish colonists soon located the alluvial gold deposits and some of the primary sources, especially Zaruma-Portovelo and Nambija. The deposits were worked using rudimentary methods and slave indian labour but with such brutality that increasing native resistance culminated in a series of revolts, forcing the colonial mining settlements to be abandoned. The settlements were mostly located along the foot of the eastern Cordillera and upper Amazon basin. These events, together with diversion of Spanish colonial interest in mining to nearby Peru and Colombia, resulted in a lull in mineral exploration and exploitation in Ecuador.

This situation continued through the wars of independence in the early 19th century and only from the 1880's onwards did mining revive, mostly in the Zaruma-Portovelo area. The latter area was worked by foreign companies (notably the South American Development Co.), until 1950, and recently became a state-owned concern.

In the early 1980's the Nambija mines were rediscovered prompting a rush to the rich primary gold deposits in the area. A disastrous wet season in 1982-1983 precipitated a further search for gold resulting in the finding of numerous auriferous areas, notably Ponce Enríquez and, more recently, Chinapintza. Current estimates for annual gold production in Ecuador are approximately 10 to 13 tonnes. This production is mostly from artisanal exploitation of alluvial and rich primary deposits. Mining by organized (often multinational) companies is restricted to two alluvial gold dredging operations in the southwest of Ecuador.

Several multinational companies are actively conducting exploration, and many more have expressed interest in Ecuador's relatively undeveloped mineral potential.

2. PRECIOUS METALS

2.1 Gold - Alluvial deposits

Alluvial gold is widespread in the drainage systems of the Cordillera Real and, in some places, this gold is exploited by artisanal miners using relatively primitive methods (see reviews by Holloway, 1932; Pillajo, 1982; Pillajo and Báez, 1983). Annual production of alluvial gold in Ecuador has been estimated at 1 - tonne per annum (for 1990; Figure 5). Occurrences of alluvial gold are reported in geological map sheets (Ecuador 1:100000 scale) No's 58, 59, 72, 75, 76, 86, 87, 90, 98, 100, 101, and 102 (Appendix B), but the unpublished map of the alluvial gold potential of Ecuador (Pillajo and Báez, 1983; 1:1 million scale) is, perhaps, the most complete and accurate review of the occurrence and distribution of alluvial gold in the country. A modified version of this map is presented in Figure 4 a, b, c.

In this report, the occurrence, distribution, and likely source(s) of alluvial gold in the Cordillera Real will be described from the south (frontier with Peru) to the north (frontier with Colombia), and each area will be numbered in the text for reference to the map (Figure 4 a, b, c):

2.1.1 Zumba-Valladolid-Vilcabamba (Figure 4a)

In the region surrounding the towns of Zumba, Valladolid and Vilcabamba, the Ríos Isimanchi, Mayo, Valladolid, Piscopamba and Nambala are classified as auriferous (Pillajo and Báez, 1983). The most productive area is in the vicinity of Zumba at the junction of the Ríos Isimanchi and Mayo and a little upstream. Small quantities of alluvial gold are said to occur in rivers in the area (Zumba geological sheet 59; Appendix B). Gold has not been examined from this area.

The geology of the catchment area comprises mostly gneissic granodiorites and medium- to high-grade meta-sediments of the Sabanilla subdivision (Loja division); semi-pelitic quartzites and black phyllites of the Chigüinda subdivision and, in the east, undeformed granodiorite and diorite (Zamora batholith, Abitagua subdivision); black and green phyllites, metatuffs and marbles (Isimanchi subdivision); and undeformed continental volcanics (Misahuallí subdivision) of the Zamora division. In the headwaters of the Río Isimanchi, Neogene granite, granodiorite, and diorite of the Portachuela batholith outcrop and, in the vicinity of Zumba, Tertiary sediments and volcanics occur.

Basement structures are dominated by the Las Aradas fault which forms the western boundary of the Portachuela batholith, and the Sabanilla and Palanda faults which flank the Sabanilla subdivision gneisses and schists.

Alluvial gold in the area is likely derived from one or more of the following primary mineralized sources:

a. Massive metamorphic-hosted quartz veins e.g. Masanamaca (Wolf, 1892; Bonilla, 1987, Quinara area), and Yangana (Jemielita, 1991b; Appendix F2).

b. Epithermal, porphyry-related, volcanic-hosted, veins and stockworks (Clarke, 1989).

c. Gold mineralized skarns related to the Zamora batholith (N.B. scheelite in pan concentrates; Clarke, 1989).

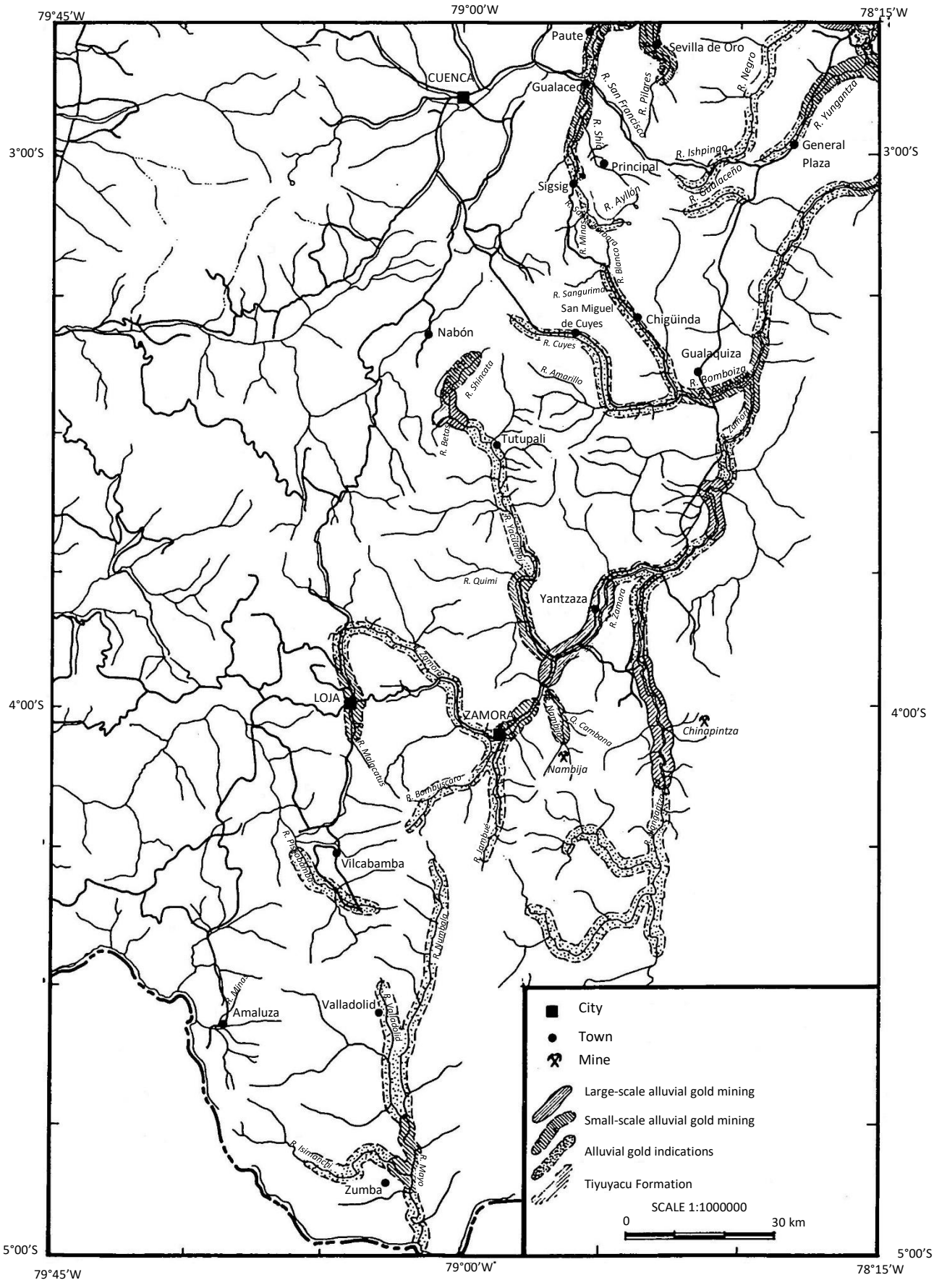

Figure 4a. Auriferous rivers in the south of the Cordillera Real

2.1.2 Amaluza - Cera - Loja (Figure 4a)

Alluvial gold occurs in the area from Amaluza northeast to La Toma and Loja, but mostly in the vicinity of Loja in the Ríos Malacatus and Zamora. The most productive sections of these rivers are immediately south and north of Loja (Pillajo and Báez, 1983). Gold is said to occur at numerous localities but only in small quantities (Las Aradas geological sheet 58; Appendix B).

The geology of this area is dominated by semipelitic quartzites and black phyllites of the Chigüinda subdivision (Loja division). In the south, and to the east of Amaluza, Neogene granodiorite with granite and diorite of the Portachuela batholith outcrops. In the north, in the vicinity of Loja, blue quartz-biotite granite or granite gneiss (Tres Lagunas subdivision), and muscovite-garnet ± graphite schists (Agoyán subdivision) of the Loja division occur. Loja itself is located within a fault-bounded basin containing Miocene sediments (UNDP, 1969a).

The dominant structure in the area is the Las Aradas fault which trends north through Las Aradas to immediately east of Catamayo where it bends north-eastwards to become the Baños fault (Aspden and Litherland, 1992; Figure 2). The Las Aradas fault is characterised by strongly deformed grey and black phyllites and quartzites (Chigüinda subdivision), often containing massive quartz ± ankerite ± sulphide veins.

Alluvial gold was examined from the Río Malacatus, about 5 km south of Loja. River boulders at this locality are dominated by grey and black pelitic schists and massive white vein quartz. The gold is deep golden yellow, medium-grained (< 3mm dia.), and comprises flat, irregular and discoid plates with moderate- to finely-pitted surfaces. Some grains are intergrown with white quartz. Alluvial gold has also been reported from the Quebrada Minas about 3 km NNE of Amaluza (David Coochey, pers. comm., 1991).

Alluvial gold in the Ríos Malacatus and Zamora near Loja is likely derived from massive quartz ± ankerite ± sulphide veins. In the vicinity of the village of Cera, northwest of Loja, veins of this composition are worked for gold (see Gold-Primary Mineralization section), and old mines exploiting similar mineralization have been reported east of Loja (Wolf, 1892).

2.1.3 Zamora - Nambija - Chinapintza - Yantzaza (Figure 4a)

The region including the towns and mining camps of Zamora, Nambija, Chinapintza and Yantzaza, in the southeast of Ecuador, currently constitutes the most extensive and active area of gold exploration and exploitation in the country. Although much of this area is, strictly speaking, outside of the Cordillera Real proper, it is included in this report due to its proximity to the project area, and its status as one of the most important mining areas in Ecuador.

The Ríos Zamora, Bomboscara, Jambué, Nambija, Yacuambí, Nanguipa, Nangaritza, Quimi and Quebrada la Ciudad are all classed as auriferous, and the Ríos Zamora, Yacuambí, Nanguipa and Nangaritza are classed as being particularly productive (Pillajo and Báez, 1983; Paquisha geological sheet 76, Appendix B). Many smaller tributaries and quebradas are also worked for alluvial gold and, since the early 1980's, the Río Nambija and Quebrada Cambana, in particular, have been exploited.

Geology in this region is dominated by a basement of undeformed granodiorites and diorites of the Jurassic Zamora batholith (Abitagua subdivision, Zamora division). The batholith envelops areas of calciferous and volcaniclastic sediments (Isimanchi subdivision, Zamora division), interpreted as Triassic-Jurassic roof pendants. In the east, especially in the vicinity of Chinapintza, the basement granodiorite is cut by younger (Tertiary?) porphyry dykes, plugs and breccia pipes and overlain by volcanic and volcaniclastic rhyolites and dacites.

The western margin of the Zamora batholith is bounded by the Méndez-Palanda fault (Figure 2). Structure within the batholith is poorly understood but the gold mineralized skarn districts in the vicinity of Nambija appear to be controlled by north-south-trending, brittle faults (Andrew Rogers, pers. comm., 1992).

Alluvial gold was examined from several locations along the Quebrada Cambana. The gold is bright golden-yellow to brownish- yellow and often coated in iron oxide. Grains are very coarse (< 2 cm. dia.) to fine grained and extremely irregular in shape, crystalline, and rolled wires. Some rounding of the grains is evident and patches of (mercury) amalgamated gold were noted. Grain morphology indicates that the alluvial gold is of nearby origin (Campanillas gold mine 1 km upstream; Grant et al., 1991).

Primary gold mineralization is widely exploited in this region and probably sources the extensive alluvial gold deposits. Types of primary mineralization encountered are:

a. Auriferous skarns (e.g. Nambija and vicinity; Figure 6; see Gold-Primary Mineralization section).

b. Epithermal polymetallic veins, breccias and disseminated mineralization (e.g. Chinapintza and vicinity; Figure 6; see Gold- Primary Mineralization section).

c. Mesothermal quartz (gold?) veins in basement schists west of the Zamora batholith.

2.1.4 Nabón - Tutupali - San Miguel de Cuyes - Chigüinda (Figure 4a)

To the south and southeast of the town of Cuenca, important alluvial gold deposits are worked between Nabón and Tutupali (Ríos Shincata and Betas, Map 2g; Jemielita, 1991b; Appendix F2), San Miguel de Cuyes and Gualaquiza (Ríos Moriré, Cuyes, Amarillo, Map 3a; Jemielita, 1991c; Appendix F3), the páramos of Matanga (Río Minas, Map 3a; Jemielita and Bolaños, 1991a; Appendix F4), and in the vicinity of the town of Chigüinda (Ríos Blanco and Sangurima, Map 3a; Jemielita, 1991c; Appendix F3). All of these rivers are classified as auriferous, the most extensive sections being in the headwaters of the Ríos Shincata (Bestión) and Betas (Pillajo and Báez, 1983). Wolf (1892), describes rich alluvial gold workings at Shingata (= Shincata), Bestión, and Matanga. Alluvial gold deposits are identified at Río Shingata and eastwards in the sediments and terraces of rivers in the Amazon region e.g. Ríos Cuyes, Bomboiza, Yacuambí, and others (Gualaquiza geological sheet 75, Appendix B). Other alluvial gold deposits are located at Ortega Alto, Espadillas, and the Río Tutupali in the Cordillera de Mango Urcu near Tutupali (Gualaquiza geological sheet 75; Appendix B; Aspden, 1990).

Geology in the area is dominated by the variably deformed quartz biotite granite or granite gneiss of the Tres Lagunas batholith (Tres Lagunas subdivision; Loja division), exposed along the watershed and western slopes of the Cordillera Real. To the east, semipelitic quartzites, and black phyllites of the Chigüinda subdivision (Loja division) predominate, followed eastwards by a south wedging slab of Upano subdivision andesitic green-stones, volcaniclastics, and greywackes. These lithologies give way eastwards to undeformed granodiorite and diorite of the Zamora batholith (Abitagua subdivision; Zamora division), but northwards the batholithic intrusives are progressively covered by undeformed continental volcanics of the Misahuallí subdivision (Zamora division). In the sub-Andean zone to the east, Cretaceous white quartzites (Hollín formation) and black limestones and shales (Napo formation) outcrop.

Contacts between the lithological subdivisions are usually transcurrent, shear zone faults or thrusts. A particularly important structure is the Baños fault (previously Baños front; Aspden and Litherland, 1992), which bounds the western margin of the Tres Lagunas batholith. This fault is thought to be a dextral, transcurrent, ductile shear zone of regional extent which can be traced along most of the western margin of the Ecuadorian Cordillera Real and northwards into Colombia. The occurrence of alluvial gold workings in rivers crossing the Baños fault, between the area of the Río Shincata in the south and the Río Collay in the north, led Aspden (in Litherland et al., 1990) to propose the existence of a (Collay-Shincata) “gold belt”.

Río Shincata (Bestión) - Río Betas: The upper reaches of the Río Shincata (east of Nabón and Cochapata, Map 2g; Jemielita, 1991b; Appendix F2), around and upstream of its junction with the Río Betas, occupy a relatively level area of low rolling hills located west of the Cordillera Real watershed. Country rocks are dominantly fine- to coarse-grained biotite schists of the Tres Lagunas subdivision or possibly the Agoyán subdivision (Loja division), and may be sheared equivalents of the Tres Lagunas granite in some instances. The area straddles the Baños fault.

Evidence of past and present alluvial gold workings occur over an area of at least 20 km by 8 km (160 km^2). The Río Shincata area is famous for gold production and has had a long history of exploitation (Wolf, 1892). Pre-colonial, possibly pre-Inca, alluvial workings are common and mechanized and artisanal alluvial mining is presently active. A fragment of pottery, possibly of pre-Inca age, was found in the mine waste and supports the antiquity of gold exploitation in the area. Workings exploit palaeo-river terraces and active river sediments.

The palaeo-river terraces comprise poorly-sorted, and poorly- to well-bedded, mature, unlithified, quartz-tourmaline pebble gravels or conglomerates (Bestión Formation of Pillajo and Báez, 1983). The pebbles comprise pure (mesothermal vein) quartz with some rounded, black, tourmaline pebbles. Quartz pebbles containing needles and masses of black tourmaline are quite common. The tourmaline pebbles are named “piedras tibias” or “warm stones” by local miners who take their presence as an indication of gold bearing material.

The alluvial gold is bright golden-yellow, fine grained (< 2 mm), and comprises extremely irregular shaped to sub-rounded, thin, flat plates, pellets and rods. Irregular shaped grains are often intergrown with quartz. Grain morphology suggests a proximal source for the gold (Grant et al., 1991). Wolf (1892), gives the following analysis for alluvial gold from Bestión: Au 89.49 %, Ag 10.38 %, and Cu plus impurities 0.13 %. Gold grade was estimated at 2.6 g/m^3 for the alluvial deposits and estimated average production was about 1 g/man/day (4.6 g/day for four men).

Some terraces, as well as the active river sediments, comprise polymict gravels containing rounded boulders of various types of grey coloured mica schist; medium to coarse-grained granitoids; sheared and brown iron oxide stained, silicic, granular rock with disseminated pyrite; fine to medium-grained dolerites; vein quartz; tourmaline pebbles, and fine gold. Many of the alluvial workings are in abandoned ox-bow terraces, but others occur tens of metres above the present river level in palaeo-river terraces.

The exact mode of formation of the auriferous quartz-tourmaline pebble gravels has yet to be established but the pebbles are, without doubt, derived from mesothermal quartz veins. Boudinaged quartz veins were noted cutting the schist basement in the area and numerous float blocks of angular vein quartz, sometimes containing tourmaline, form linear features (delineating veins) crossing the páramo. The quartz-tourmaline association is, therefore, common to the palaeo-river terrace alluvial deposits and the basement-hosted veins. The mesothermal veins are the most likely source for the alluvial gold.

Quartz and tourmaline pebbles occur commonly in (often auriferous) alluvium from the Río San Antonio, 15 km ENE of Saraguro, through the Río Betas-Río Shincata area, northeast to the Río Minas, east of Gima, a distance of 50 km along the strike of the Baños fault. Basement in this area comprises strongly sheared Tres Lagunas granite, and tourmaline, apparently, only occurs in mesothermal quartz veins and quartz pebble gravels where the Baños fault cuts the Tres Lagunas batholith.

Río Cuyes - Río Moriré: The town of San Miguel de Cuyes is built on the north bank of the auriferous Río Cuyes which drains the eastern slopes of the Cordillera Real to the northeast of the Shincata-Betas area (Map 3a; Appendix F3).

Basement lithologies in the area are dominated by mica schists of the Chigüinda subdivision and both deformed and undeformed Tres Lagunas granite. The basement is intruded, in places, by small biotite-feldspar-phyric plugs, and unconformably overlain by younger volcanic and volcaniclastic rocks.

Alluvial gold is worked seasonally by local farmers in the Río Moriré and Río Cuyes (Map 3a), and the Río Amarillo downstream (9 km west of Nueva Tarqui) is also said to be auriferous. The gold is probably restricted to active river gravels because no extensive terrace deposits were observed.

Gold was examined from the Río Cuyes and is deep golden-yellow, with iron oxide coating some grains. The gold is medium- to fine-grained (< 7 mm. dia.), and comprises thin to moderately thick discs, elongate to irregular shaped plates, pellets and irregular grains (crystal moulds?). Surfaces are moderately to coarsely pitted, and some gold grains are intergrown with quartz. Grains vary from well- to poorly-waterworn.

The Río Moriré is a tributary of the Río Cuyes and is, apparently, worked for alluvial gold. River boulders comprise purple-grey, fine-grained, mica schists, together with abundant white vein quartz. Coarse (< 2 metres diameter), angular, white vein quartz is fairly common as float in nearby fields. Stream sediment samples were taken but no gold was noted in pan concentrates. Local people claim that the Río Moriré is rich in gold but no miners were working at the time of the visit due to the winter season.

The alluvial gold likely originates from shear zone-hosted, mesothermal quartz (± tourmaline) veins which are commonly observed as angular float and rounded river boulders in the area. Other primary mineralization observed includes disseminated and veinlet pyrite in sericite schists, and granular, siliceous, fine-grained intrusive rocks. There may be potential for disseminated sulphide and/or porphyry-related mineralization in the area, and some alluvial gold may originate from these sources.

Río Blanco - Río Sangurima: The Río Blanco is a tributary of the Río Sangurima and both rivers are substantial and historical alluvial gold producers. The rivers are located in the vicinity of the village of Chigüinda, about 45 km southeast of Cuenca (Figure 4a; Map 3a; Jemielita, 1991c; Appendix F3).

Basement lithologies comprise semipelitic quartzites and black phyllites of the Chigüinda subdivision (Loja division), intruded, in places, by small plugs of Tertiary granodiorite. Geologically, the area is a northeast extension of the San Miguel de Cuyes area.

Structure is dominated by the Andean-trending schistosity of the (Chigüinda subdivision) basement lithologies, and these are bounded by the sub-Andean fault to the east and an un-named fault to the west.

According to local information, up to 300 men work alluvial gold deposits in the Río Blanco, and the Río Sangurima. Average production of 10 grams of gold per claim, per day, was estimated, but greater production was not considered uncommon. Nuggets of up to 300 grams have been found. Gold is frequently found along with sub-angular to rounded pebbles of magnetite-rich schist. These are known locally as “piedras tibias” or “warm stones” because their presence is regarded as a sign that the prospect is “warm” for gold. Gold from the Río Blanco is deep golden-yellow, and iron oxide coats some grains. The gold is very coarse to fine (> 1.7 cm. dia.), and forms elongate to discoid, thick but flat plates, and some pellets. Large grains are well rounded and finely pitted, but smaller grains are moderately to coarsely pitted.

The Río Blanco seems to be the main source of gold in the Chigüinda area and accounts for the gold workings in the Río Sangurima which are only to be found downstream of the junction of the two rivers.

River boulders in the Río Blanco comprise volcanic rocks, granitoids (including Tres Lagunas granite), black and grey mica schists, and massive, mesothermal vein quartz. The presence of the latter boulders supports a mesothermal quartz vein source for the alluvial gold. The absence of tourmaline, and the presence of magnetite rich “piedras tibias” suggests, however, that the nature of the gold source may be somewhat different to that of other areas located southwest along the Baños fault e.g. Río Shincata-Río Betas. The common presence of young porphyritic boulders in the Río Blanco could also indicate porphyry-related mineralization as a potential primary gold source. Further studies will be necessary to confirm the source of the gold.

Matanga - Río Minas: The páramos of Matanga area is located in the headwaters of the Río Minas (Maps 3a, 4a; Jemielita and Bolaños, 1991a; Appendix F4) approximately 13 km south of the town of Sigsig. Altitude is around 3215 metres and local topography is moderately steep. The area was previously described as being a rich alluvial gold producer (Wolf, 1892).

Basement lithologies comprise mica schists (Tres Lagunas subdivision), and semipelitic quartzites and black phyllites (Chigüinda subdivision) of the Loja division. Young volcanic rocks blanket the basement lithologies in places and are, themselves, sometimes overlain by quartz pebble gravels.

Structure is dominated by the Andean-trending schistosity of the basement lithologies, and the area straddles the tectonic contact between the Tres Lagunas and Chigüinda subdivisions.

An alluvial gold mine was visited which is presently being exploited by a cooperative of five men. The auriferous material comprises a moderately coarse boulder gravel of alluvial and colluvial origin. Boulders comprise mostly silver-grey mica schists; white, mesothermal vein quartz; and some altered and rotted recent volcanics.

Heavy minerals are abundant in pan concentrates and the gold is golden-yellow-brown, medium to fine grained (< 5 mm. dia.), extremely irregularly shaped with sharp edges to sub-rounded. Grains occur as equant masses, plates, subrounded pellets and nuggets. Surfaces are fine to coarsely pitted. Gold is often seen in quartz matrix with red hematite staining. Red hematite-stained particles are fairly common. Gold morphology suggests little transport of the grains (Grant et al., 1991). “Piedras tibias” of garnetiferous rock were observed. The miners claim to have found nuggets of up to 3 grammes in weight.

The composition of the alluvial/colluvial boulders reflects that of the underlying basement (Tres Lagunas and Chigüinda subdivisions) and, together with the morphology of the alluvial gold, indicates that the alluvial/colluvial gold likely derives from nearby mesothermal quartz veins in the basement schists.

2.1.5 Sigsig - Principal - Gualaceo - Sevilla de Oro (Figure 4a)

Rivers in this area figure prominently in Wolf (1892), who describes rich alluvial gold deposits in the Ríos Ayllón, Santa Bárbara and Collay, and poor deposits in the headwaters of the Ríos Gualaceo, Alcacay, Shiu, Guallmincay, and San Francisco (Map 4a; Jemielita and Bolaños, 1991a; Appendix F4). The Ríos Santa Bárbara and Ayllón are located about 35 km southeast of Cuenca (Map 4a).

Río Santa Bárbara - Río Ayllón: The geology of the Río Santa Bárbara-Río Ayllón area comprises, from west to east, Tertiary volcanic and volcaniclastic lithologies of the inter-Andean graben; andesitic greenstones and metasediments of the Alao-Paute subdivision (Alao division); and mica schists of the Tres Lagunas subdivision and semipelitic quartzites and black phyllites of the Chigüinda subdivision (Loja division). At Mina Peggy, about 5 km south of Sigsig, minor intrusions of Tertiary rhyolite porphyry cut the basement schists.

Structure is dominated by the Andean-trending schistosity of the basement lithologies. The area straddles the Baños fault and the tectonic contact between the Tres Lagunas and Chigüinda subdivisions. The course of the Río Ayllón appears to be controlled by an Andean-trending structure.

River boulders in the Río Santa Bárbara, upstream of the junction with the Río Ayllón, comprise mica schists and fine- to medium-grained granitoids. Mineralized boulders include silicified mica schist and sericite schist with spots of fine-grained pyrite (sometimes with a breccia texture). Massive, mesothermal vein quartz is quite common. Alluvial boulders in the Río Ayllón, upstream of the junction with the Santa Bárbara, comprise mica schists and psammitic schists; massive, mesothermal vein quartz; fine-grained volcanic rocks and porphyries; and medium-grained granodiorites. Boulders of white vein quartz with coarse arsenopyrite were observed, and similar boulders occur downstream in the Río Santa Bárbara as far as the Mina Peggy. Clarke (1989) reported a gold value of 5.2 g/T for a similar sample. At the junction of the rivers, and downstream, similar boulder lithologies were noted and other lithologies include some greenschist and (Tres Lagunas) granite. One mineralized boulder of pyrite-arsenopyrite-bearing vein quartz had an alteration envelope of sericite peppered with small garnet crystals. Pebbles of red-green, garnet epidote rock, and brown, banded, magnetite schist were noted.

In the vicinity of the junction of the Ríos Santa Bárbara and Ayllón, alluvial gold deposits and rich auriferous quartz veins are presently being mined by artisanal methods. Mining is conducted by cooperatives comprising various numbers of individuals who exploit the alluvial/colluvial river banks and river bed gravels, as well as mineralized veins. Waste boulders are often built into walls which give a good indication of the considerable labour that has been employed in the area.

Gold from the Río Ayllón and Río Santa Bárbara, when observed, was seen to be medium grained and good quality. Gold from the tributary Quebrada Obscura is reputed to be very coarse. Wolf (1892) gives the following analysis for alluvial gold from the Río Ayllón: Au 84.27 %, Ag 14.71 %, Cu plus impurities 1.02 %. A gold grain from the Río Ayllón river bed was observed to be silver-coloured at one end due to amalgamation with mercury. The mercury in the river is likely a result of its use for amalgamation by the miners. Gold was panned nearby from coarse, iron oxide-stained alluvium on the south bank of the Río Santa Bárbara where there are moderately extensive excavations. No miners were working at the time of the visit due to bad weather. The alluvial gold seems to be angular in the vicinity of the junction of the rivers but forms small disc-like plates downstream in the Río Santa Bárbara in the vicinity of Mina Peggy. Alluvial gold from this latter location is golden-yellow, medium-grained (< 4 mm. dia), and forms thin, flat discs, occasionally very irregularly shaped, with fine to medium-pitted surfaces.

A variety of types of auriferous and potentially gold- bearing primary mineralization occur in the area. The occurrence of discordant, brittle-fracture filling, quartz-ankerite veins with arsenopyrite and other sulphides, which yield high gold values in assay (Clarke, 1989; see Gold-primary mineralization section), suggests that these veins are a probable source for much of the alluvial gold in the Río Ayllón and Río Santa Bárbara drainage systems. This is supported by the relatively common occurrence of vein quartz-arsenopyrite-sulphide-sulphosalt boulders in the river alluvium. However, the presence of relatively common mesothermal vein quartz in outcrop and alluvium could provide an additional source for alluvial gold, similar to that proposed for the Matanga area. The mesothermal quartz veins are likely associated with hydrothermal activity related to shearing along the Baños fault. In addition, the occurrence of sulphide (pyrite)-bearing sericitic and silicified schists indicates another type of primary mineralization, as yet untested for gold and other potentially economic metals.

Principal - Río Shio: The alluvial mining area of Principal is located about 2 km ESE of the pueblo of Principal in the vicinity of the junction of the Río de la Burra Playa and the Quebrada Chorro Blanco where they join to form the Río Shio (Map 4a; Jemielita and Bolaños, 1991a: Appendix F4). The rivers drain the western slopes of the Cordillera Real, west of the watershed.

Geology comprises basement of (Alao-Paute subdivision; Alao division) andesitic greenstones and metasediments, followed eastwards by (Chigüinda subdivision) semipelitic quartzites, black phyllites and greenschists, tectonically interleaved with (Tres Lagunas subdivision) granite of the Loja division. To the west, the basement lithologies are extensively overlain by Tertiary andesitic-rhyolitic volcanic and volcaniclastic rocks of the inter-Andean graben.

Basement structure is complex and the area straddles the Baños fault and several splays from the fault. The Tertiary volcanic and volcaniclastic lithologies are generally flat-lying or shallow-dipping.

In the Río de la Burra Playa alluvial boulders comprise grey-green mica schist; quartz-sericite schist; feldspathic augen schist; sheared (Tres Lagunas) granite; diorite; granite pegmatite; and massive, mesothermal vein quartz. Large boulders of coarse, rhyolitic volcanic breccia, and large, irregularly- shaped, iron oxide-stained blocks of medium-grained, grey-white, silicified and pyritized, matrix-supported volcanic/intrusive breccia are very common. In Quebrada Chorro Blanco alluvial boulders include grey-green mica schist; epidotite; feldspathic augen schist; diorite; andesite; feldspar porphyry; and white, altered volcanic rocks. Massive, mesothermal vein quartz was noted, often within epidotite, and associated with chlorite and calcite.

Gold is, reportedly, won from the Río de la Burra Playa and one tributary is known as the Quebrada Minas. An alluvial gold mine was examined on the south bank of the Río Shio immediately downstream of the junction of the Río de la Burra Playa and Quebrada Chorro Blanco. Gold is won from a pit about 3 to 4 metres deep dug into coarse river-terrace alluvium of rounded boulders and gravel, partially cemented with granular pyrite which gives the alluvium its grey colour and sulphurous odour. Mineralized boulders include fine to medium-grained, grey-green schist with disseminated pyrite; grey-white, silicified schist/quartzite with disseminated pyrite; dark grey, feldspar- phyric porphyry with disseminated pyrite; dark grey, granular, quartz-pyrite rock with quartz veinlets; grey-green mica/tremolite rock with disseminated pyrite; and grey-white, massive, mesothermal vein quartz with fine grained sulphides in places. The auriferous horizon lies below about 5 metres of this pyrite rich alluvium. “Piedras tibias” of grey quartz-pyrite pebbles with crystal lined vugs are fairly common, and pan concentrates from the mine are dominated by fine- to medium-grained pyrite sand and gold.

Gold from the mine comprises dull, golden-yellow-brown and greenish-yellow, medium- to coarse-grained (< 1 cm. long), irregular, sub-rounded plates and pellets, with fine to very coarsely pitted surfaces. Some grains are intergrown with quartz. Surfaces are commonly coated with fine-grained pyrite or iron oxides which largely accounts for the colour of the gold.

The Río Shio alluvium is the most pyrite-rich alluvium yet encountered in the Cordillera Real. The origin(s) of this pyrite and sulphide-rich, granular, quartz-pyrite rock, breccia and "piedras tibias" is, likely, Quaternary (Tarqui Formation) rhyolitic volcanics which are common in the area. The sulphide mineralization is epithermal in character and the alluvial gold may originate from this source. Disseminated pyrite is also associated with the metamorphic lithologies in the area e.g. sulphide-mineralized, mica schist-fragmental breccia, and this could be an additional, or alternative, source for the alluvial gold. Mesothermal vein quartz, the probable source for much of the gold found along the Baños fault, is a further candidate for the origin of some, or all, of the Río Shio alluvial gold. At present, these potential sources cannot be discriminated with confidence.

Río San Francisco: The Río San Francisco lies east of the town of Gualaceo (Map 4a; Jemielita and Bolaños, 1991a; Appendix F4) and is auriferous. Wolf (1892) describes the alluvial gold deposits as being poor.

The geology of the area comprises andesitic greenstones and metasediments (Alao-Paute subdivision), and greenschists and pelitic and graphitic metasediments (El Pan subdivision), of the Alao division to the west. Eastwards, semipelitic quartzites, black phyllites and greenschists (Chigüinda subdivision), and (Tres Lagunas subdivision) granite of the Loja division occur.

Structure is complex and the area straddles the Baños fault and several splays from the fault.

An active alluvial mine was visited in the upper reaches of the Río San Francisco where there is much evidence of previous workings. A cooperative of twelve men and boys work coarse alluvial gravels on the south bank of the river by artisanal methods. Alluvial boulders comprise coarse, angular to rounded blocks dominated by medium-grained, green-coloured schists, medium-grained, grey-green granodiorites, and some white sericite schists. Grey, silicified mylonites were also observed, and massive green epidotite is common. Purple-grey to white, massive, mesothermal vein quartz, often with white inclusion planes, is quite common.

Pan concentrates are rich in heavy minerals. Alluvial gold is deep golden-yellow, medium- to fine-grained (< 6 mm. long), irregular, flattened or equant, sub-rounded plates, pellets and nuggets. Gold is sometimes intergrown with quartz. The grains have fine- to coarsely-pitted surfaces, often with red-brown iron oxide coatings, and are moderately waterworn. Wolf (1892), gives the following analysis for alluvial gold from the Río San Francisco: Au 91.05 %, Ag 7.73 %, Cu plus impurities 1.22 %.

The dominance of greenschist boulders in the Río San Francisco alluvium indicates a basement source in the Alao-Paute subdivision (Alao division). Massive vein quartz commonly occurs as alluvial boulders and the alluvial gold is most likely derived from mesothermal quartz veins cutting the basement lithologies. The alluvial gold deposits are not large enough to warrant more mechanized production but there may be potential for economic primary mineralization in the basement source area.

Río Ishpingo: The Río Ishpingo is located east of the Río San Francisco, across the watershed of the Cordillera Real, and is accessible along the road leading east to Indanza (Map 4a; Jemielita and Bolaños, 1991a; Appendix F4).

Geology comprises semipelitic quartzites, black phyllites and greenschists of the Chigüinda subdivision (Loja division). A small, mineralized and hydrothermally-altered, Tertiary granodiorite pluton outcrops nearby along the Indanza road.

Structure is dominated by the Andean-trending foliation of the basement schists and an Andean-trending (Río Ayllón) fault has been mapped in the area.

An alluvial mine, operated by one man and two boys, was visited at an altitude of ca. 2800 metres. The miners exploit coarse alluvium in the river bed, consisting of rounded to angular and discoid boulders of fine-grained, silver-grey to dark grey-black mica schists; fine- to medium-grained, grey-green granodiorite/diorite; grey, silicified mica schist, and an unusual porphyritic/porphyroblastic rock with coarse sub-angular grey feldspar crystals. Greenschist boulders occur but are less common. White mesothermal vein quartz boulders with white inclusion planes and mica schist inclusions are also present.

The alluvial gold is deep golden yellow-brown, rarely bright golden yellow/yellow green, medium- to coarse-grained (< 1 cm. long), irregular, sub-rounded, sometimes partly flattened, angular or rolled/folded pellets and thick plates, with medium- to coarsely-pitted surfaces, and red-brown iron oxide coatings in places. The gold is a little waterworn but some grains exhibit crystal moulds.

The alluvial boulders are mostly derived from basement of the Chigüinda subdivision (Loja division), and the gold probably originates from mesothermal quartz veins cutting the basement.

Río Gualaceño: The Río Gualaceño is a tributary of the Río Ishpingo which drains NE from the watershed and eastern slopes of the Cordillera Real towards the Oriente (Map 4a; Jemielita and Bolaños, 1991a; Appendix F4).

Geology comprises grey-black mica schists of the Chigüinda subdivision (Loja division), cut occasionally by variably deformed, white, mesothermal quartz veins. Structure is dominated by the Andean-trending foliation of the basement schists.

The Río Gualaceño is auriferous and has several abandoned and active alluvial terrace workings in its lower reaches. Gold is worked from coarse alluvium which forms river terraces, often adhering to steep bedrock faces. Alluvial terrace boulders comprise rounded to sub-angular, grey mica schists; grey, silicified/quartz-veined schists; medium-grained, granular, and porphyritic granodiorites and diorites; and mesothermal vein quartz. Boulders are set in a gravel and clay matrix. Silicified schists are particularly common.

Heavy minerals are abundant in pan concentrates and the alluvial gold is deep golden-yellow-brown, occasionally bright golden yellow, medium to fine-grained (< 7 mm. dia.), thin to thick, discoid to elongate or irregular-shaped plates, pellets, and wires. Bright, golden-yellow grains tend to be more equant, irregular-shaped nuggets and masses with crystal moulds and are sometimes intergrown with quartz. Brown-red iron oxides commonly coat surfaces which are medium- to coarsely-pitted. The gold is well waterworn except for the bright yellow examples.

Gold is most likely derived from mesothermal, quartz veins which cut the basement lithologies in the catchment area of the river.

Río Collay (Río Pilares - Quebrada Huagrarumi): The Río Collay is located south of the town of Sevilla de Oro, about 40 km ENE of Cuenca (Map 4a; Jemielita and Bolaños, 1991a, b; Appendices F4 and F5), and is one of the most famous, and historically referenced, gold-producing rivers in Ecuador (Wolf, 1892; Navarro, 1986). Wolf (1892) classified the Río Collay as a rich alluvial gold producer, and mentioned that gold was associated with mercury which he considered to be natural in origin.

Geology comprises tectonically interleaved (Tres Lagunas subdivision) granite, semipelitic quartzites, black phyllites and greenschists (Chigüinda subdivision) of the Loja division, and greenschists and pelitic and graphitic metasediments (El Pan subdivision, Alao division). The headwaters of the Río Pilares, a tributary of the Collay, drain andesitic greenstones and metasediments of the Alao-Paute subdivision (Alao division). The basement schists are overlain, in places, by Tertiary andesitic-rhyolitic volcanic rocks, and a rhyolite dyke and porphyry (intrusive) breccia have been noted.

Structure is dominated by the Andean-trending foliation of the basement schists and tectonic contacts between different lithologies. The orientation of the Río Collay likely reflects one of the latter structures.

Río Pilares alluvial boulders comprise grey-black, semi-pelitic mica schists; massive, mesothermal vein quartz (± ankerite); a variety of porphyries and volcanic rocks (sometimes silicified); and, less commonly, (Tres Lagunas) granite and granular greenschist. Quebrada Huagrarumi is dominated by boulders of greenschist; epidotite; and massive, mesothermal vein quartz, often with greenschist inclusions, Volcanic lithologies are also common but grey-black, graphitic schists are rare.

Gold is worked from active river bed alluvium and alluvial terraces. At the junction of the Río Pilares and Quebrada Huagrarumi (both rivers join to form the Río Collay) there are extensive abandoned terrace workings. Alluvial mines were observed in operation in the Río Pilares a few hundred metres upstream of its junction with the Quebrada Huagrarumi. The upstream mine, employing about twelve men, was not visited. The downstream mine (Sociedad Cari Collay) employs thirty men who had excavated a five-metre-deep pit in the middle of the river. The pit exposed a bedrock of yellow-brown coloured, clay-altered, volcanic rock and auriferous alluvium.

Gold from the mine is deep golden-yellow, moderately coarse to fine (< 8 mm. long; up to 0.5 g grains claimed by the miners), and typically comprises thin or thick, flattened, sub-rounded, discoid plates, rolled elongate irregular wires and pellets, and extremely irregular masses. Dark brown iron oxides sometimes coat grain surfaces which are finely to very coarsely pitted. Some (bright yellow) grains are intergrown with quartz and some exhibit crystal moulds. Associated heavy minerals appear to be rich in pyrite.

Wolf (1892) gives the following analysis for alluvial gold from the Río Collay: Au 82.16 %, Ag 17.24 %, Cu plus impurities 0.60 %. He further calculated that the various alluvial terraces in the area contained between 0.130 and 0.563 g/m^3 gold, and between 0.522 and 0.760 g/m^3 mercury.

Observed production from half a day of work amounted to only 5.3 grammes, a poor yield for thirty men. The miners claim that the gold in this locality is relatively fine-grained but becomes finer downstream and much coarser (up to 125 g nuggets) upstream in the Pilares near lakes at the headwaters of the river. These claims were not confirmed.

Another pit was being prepared by a cooperative of twelve men at the junction of the Río Pilares and the Quebrada Huagrarumi where they join to form the Río Collay. No gold or heavy mineral samples were available for examination but many angular to sub-angular blocks of porous, silicified, grey-beige-brown-coloured porphyry-breccia, with very fine-grained pyrite in the unoxidized (grey) areas, were observed. These samples are very common and represent an acid-leached, epithermal-mineralized, porphyry-breccia. Lithologies displaying this type of composition and mineralization have very good precious metals potential. In addition, blocks of banded and porous iron oxide gossan were observed in the Río Huagrarumi, immediately upstream of the junction, and these may be indicative of sulphide mineralization in the vicinity.

A few hundred metres downstream of the Río Pilares-Quebrada Huagrarumi junction another pit was being excavated by twelve men in the riverbed. Bedrock exposed in this pit comprises grey mica schists, and much angular, brown, iron oxide-stained, grey-yellow, pyritized mica schist occurs in this vicinity. The latter material is probably derived from a mineralized schist exposure on the actively eroding (west) bank of the river. This strongly pyritized schist lithology could have potential as a source of gold and other metals.

The origin of much of the alluvial gold in the Río Collay-Río Pilares area can be attributed to mesothermal quartz veins in the extensive drainage catchment area. This is supported by the dominance of schists and mesothermal vein quartz in the rivers. Nevertheless, the occurrence of volcanic rocks and rhyolite intrusions, together with the discovery of acid leached, pyritized porphyry breccia and gossan, is strong supporting evidence for the existence of epithermal-type mineralization, a possible contributor to the gold budget of the rivers. This is further supported by the occurrence of supposedly natural mercury in the terrace alluvium of the Río Collay (Wolf, 1892), because mercury is a characteristic metal in some epithermal-type precious metals deposits (Clarke and Govett, 1990).

2.1.6 Paute - Méndez (Figure 4b)

The town of Méndez is located near the junction of the Ríos Paute, Negro, Yunganza and Upano which unite to form the Río Namangoza, known downstream as the Río Santiago, one of the principal rivers of the Ecuadorian Oriente. All of these rivers are auriferous (Pillajo and Báez, 1983), and are exploited for gold to a greater or lesser extent. The town of Logroño, located in this vicinity, has long been reputed as one of the principal colonial gold centres of Ecuador (Navarro, 1986; Villavicencio, 1858).

The geology of the catchment area of the Ríos Paute, Negro and Yunganza comprises mostly andesitic greenstones, volcaniclastics, greywackes, pelitic and graphitic schists of the Upano subdivision (Salado division). The upper reaches of these rivers, but especially the Río Paute, drain a range of lithologies belonging to the Chigüinda and Tres Lagunas subdivisions (Loja division), and the El Pan and Alao-Paute subdivisions (Alao division). These basement rocks are intruded, in places, by Tertiary granodiorite plutons and, at one locality, by a late Cretaceous ultramafic plug (Tampanchi). The Río Paute has headwaters in the Miocene sedimentary basin of Cuenca, and is one of the few rivers which cuts completely across the Cordillera Real from west to east. Near their junction, the Ríos Paute, Negro, Yunganza and Upano cross Cretaceous and younger sediments of the sub-Andean zone.

Structure is dominated by the Andean-trending foliation of the basement lithologies and tectonic (shear zone) contacts separating the different basement subdivisions. The Baños fault is a conspicuous example of the latter structures. In the sub- Andean zone, thrust faulting affects the Cretaceous and younger sedimentary lithologies.

Ríos Paute, Negro, Yunganza and Santiago: The Río Paute and, especially, the Ríos Yunganza and Negro are classified as auriferous, with the most productive areas being in the Río Yunganza immediately upstream of the junction with the Río Namangoza, and the Río Negro, immediately upstream of the junction with the Río Paute (Pillajo and Báez, 1983). These rivers join the auriferous Río Upano near Méndez, and alluvial gold exploitation also takes place downstream in the Río Santiago, especially around and downriver of the junction with the gold-rich Río Zamora. The area has not been examined in detail but the catchment area of these rivers lies along strike to the northeast of the Sigsig-Sevilla de Oro area (see preceding section 5), and the source of alluvial gold is likely to be similar in both. Tributaries of the Río Paute in its upper reaches include the auriferous Ríos Santa Bárbara, San Francisco and Collay, and the Río Macas (Taday) is also said to be gold- bearing (Cañar geological sheet 72; Appendix B).

2.1.7 Macas (Figure 4b)

The Ríos Upano and Abanico are located in the vicinity of the town of Macas (Map 5a; Jemielita and Bolaños, 1991b; Appendix F5), and are classified as auriferous (Pillajo and Báez, 1983; Macas geological sheet 90, Appendix B).

The geology of the catchment area of these rivers comprises a complete cross section of the Cordillera Real. Basement lithologies drained by the rivers include (from west to east) andesitic greenstones and metasediments (Alao-Paute subdivision, Alao division); muscovite-garnet ± graphite schists (Agoyán subdivision), semipelitic quartzites and black phyllites (Chigüinda subdivision), and (Tres Lagunas subdivision) granite of the Loja division; and andesitic greenstones, volcaniclastics, greywackes, pelitic and graphitic schists (Upano subdivision), of the Salado division. At the junction of the Ríos Abanico and Upano and downstream, country rocks comprise Cretaceous Hollín and Napo formation sediments. Large Tertiary granodiorite plutons intrude Upano subdivision lithologies along both rivers.

Structure is dominated by the Andean-trending foliation of the basement lithologies and tectonic (shear zone) contacts separating different basement subdivisions. In the subandean zone, thrust faulting affects the Cretaceous and younger sedimentary lithologies.

Río Upano: Alluvial gold is worked in the Río Upano. The alluvial mines were not being operated and were not visited, but gold was observed belonging to miners in the nearby village of 9 de Octubre. The gold is a deep to bright golden-yellow and is typically fine- to medium-grained (< 3 mm. dia.) and comprises small circular and irregular, but rounded, flattened plates with fine- to medium-pitted surfaces. Alluvial gold is, apparently, also mined from the nearby Río Abanico.

Primary mineralization observed in the area comprises variably sulphide-mineralized, hydrothermally altered and weathered metasediments and meta-volcanics, intruded by a generally fresh and variably sulphide mineralized composite diorite-granodiorite pluton (Salado intrusion). Epithermal quartz veins, often with associated sulphides, are commonly associated with this intrusion-related mineralization. The Upano subdivision is a known host for auriferous volcanogenic massive sulphide mineralization (e.g. Guarumales, see Cu, Pb, Zn section). Mesothermal quartz veins cut the basement schists in places, especially within high strain (shear) zones e.g. Laguna Negra shear zone near Atillo (Map 5b).

Alluvial gold in the Ríos Upano and Abanico may be derived from one, or a combination, of the types of primary mineralization described above.

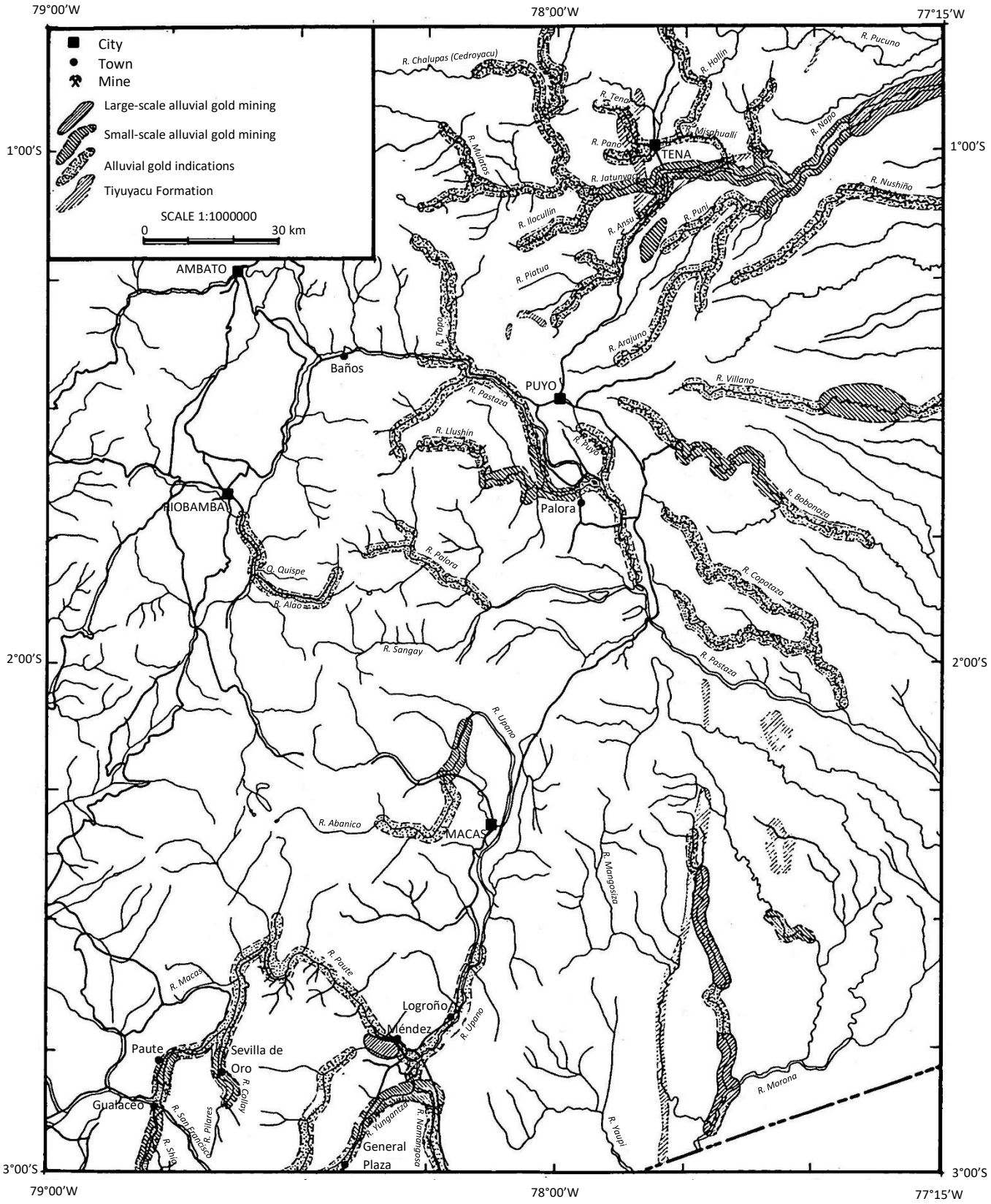

Figure 4b. Auriferous rivers in the central part of the Cordillera Real

2.1.8 Riobamba (Figure 4b)

The Río Alao drains the western slopes of the Cordillera Real southeast of Riobamba and is classified as being auriferous (Pillajo and Báez, 1983).

The geology of the Río Alao catchment area comprises (from west to east) Tertiary to Recent volcanics of the inter-Andean graben; black slates and quartzites (Cebadas subdivision, Guamote division); ophiolitic, tectonic melange (Peltetec subdivision), turbidites, andesites, cherts and marbles (Maguazo subdivision), and andesitic greenstones and metasediments (Alao-Paute subdivision) of the Alao division; and granite or granite gneiss (Tres Lagunas subdivision, Loja division). These lithologies are intruded, in places, by Tertiary granodiorite plutons and a Quaternary porphyry dyke.

Structure in the area is dominated by Andean-trending foliation in the basement schists and tectonic (shear zone) contacts between, and within, different lithological subdivisions e.g. the Peltetec, San Antonio and Baños faults. The Baños fault has been interpreted as a terrane boundary or suture (Litherland and Aspden, 1992), and the Peltetec fault corresponds with an ophiolitic melange (Peltetec subdivision), within accretionary prism sediments.

The Río Alao (Map 1) has, apparently, previously been worked for gold by dredging (Alex. Hirtz, pers. comm., 1991), but no alluvial gold mining is presently in operation.

Alluvial gold occurs in the quebrada Quishpe, immediately to the north of the Río Alao (Map 1), and a small mining operation has been operating until recently. Gold is won from a very poorly sorted colluvium/alluvium comprising coarse, angular fragments of white and grey, altered porphyry or silicified granodiorite; granodiorite; andalusite schist (hornfels); black schist; massive vein quartz; and purple andesite porphyry.

The gold is bright golden-yellow, medium to fine-grained (< 4 mm. long), and comprises rounded, irregular-shaped plates, discs and pellets, as well as extremely irregular or crystalline grains, often intergrown with quartz and exhibiting crystal moulds. Grain surfaces range from smooth to fine- or coarsely-pitted. The alluvial gold is associated with a grey metallic mineral identified as bismuth telluride. (Sr. Alex. Hirtz, pers. comm, 1991).

The quebrada Quishpe drains a fractured, hydrothermally- altered and mineralized, Tertiary, biotite-hornblende granodiorite intrusion which hosts auriferous polymetallic veins (see Gold-primary mineralization section), the likely source for the alluvial gold.

Possible sources for alluvial gold in the Río Alao area (Map 1; Jemielita, 1991a; Appendix F1) include volcanogenic massive sulphide deposits (e.g. Mina Pilas), mesothermal quartz veins (e.g. Baños fault-hosted), polymetallic quartz veins (e.g. Mina Curiayana) and, possibly, sediment-hosted, syngenetic mineralization (e.g. Quebrada Huarguallá Cu mineralization; also see Gold-primary mineralization section).

2.1.9 Palora (Figure 4b)

The Río Palora drains the eastern slopes of the Cordillera Real across the watershed from the westward-flowing Río Alao. The Río Llushín is located immediately to the north of the Río Palora (Map 8a; Jemielita, 1992; Appendix F8), and both rivers are classified as auriferous (Pillajo and Báez, 1983).

Geology in the catchment area comprises (from west to east) Quaternary to Recent volcanics of the El Altar and Sangay volcanos; granite or granite gneiss (Tres Lagunas subdivision), muscovite-garnet ± graphite schists (Agoyán subdivision), and semi-pelitic quartzites and black phyllites (Chigüinda subdivision) of the Loja division; deformed granodiorite (Azafrán subdivision), and andesitic greenstones, volcaniclastics, and greywackes (Upano subdivision) of the Salado division. To the east, in the sub-Andean zone, Cretaceous sediments of the Hollín, Napo and Tena Formations are tectonically interleaved with Upano subdivision lithologies. The lower reaches of some river valleys are partially filled with volcaniclastic sedimentary rocks (e.g. andesitic lahars in the Ríos. Palora, Sangay and Llushín), overlain by (auriferous) alluvial terrace deposits.

Structure in the area is dominated by Andean-trending foliation in the basement schists and tectonic (shear zone or thrust fault) contacts between, and within, different lithological subdivisions. Two notable examples are the Cosanga fault and the sub-Andean fault.

Río Palora: The area of the Río Palora examined lies upstream of the junction with the Río Sangay and downstream of the Río Benado (Map 8a). Exposures in the area comprise recent (probably Pleistocene-Holocene) volcaniclastic lahar overlain by a veneer of poorly consolidated and auriferous, polymictic, boulder alluvium. These lithologies appear to fill the wide, flat-bottomed (terraced) valleys of the Río Palora and Río Sangay. The terraces and lahar deposits have been incised by the Río Palora and its tributaries and the active river alluvium is also auriferous. The lahar deposits are, likely, derived from the active volcano Sangay or, possibly, the formerly active volcano El Altar to the south-west and west respectively. The alluvial terrace deposits and active river alluvium are derived from mixed (Cordillera Real basement) batholithic granitoid, semi-pelitic, pelitic and greenschist metamorphic source, as well as sedimentary lithologies (Napo Formation) of the sub-Andean zone.

In the Río Palora, gold is washed from the poorly consolidated alluvium, especially the lower layers near the contact with the underlying lahar breccias, as well as the active river sediments. This section of the Río Palora is the most productive and is said to support about sixty miners at the peak of the mining season. Up to 5 g/day per man of gold was said to be normal production. No miners were working at the time of the visit but alluvial gold operation have previously been observed in the area (Aspden, 1990), and the river is classified as being auriferous (Pillajo and Báez, 1983). Alluvial gold was examined from three locations. The alluvium appears to be quite rich and yielded about 10 colours per pan when sampled.

The gold is medium- to fine-grained (< 3 mm across) and deep yellow in colour. Grains are commonly flattened, rounded, irregular, and elongate plates, and their surfaces are marked by fine- to medium-pitting. The samples examined may not be representative of gold produced during alluvial mining when coarser gold may be recovered.

Río Llushín: The Río Llushín was examined up to 3 km west of the junction with the Río Pastaza (Map 8b). This part of the river is auriferous (Pillajo and Báez, 1983), and is exploited seasonally by artisanal miners.

Geology in this area is similar to that of the Río Palora and comprises andesitic lahar deposits overlain by (auriferous) terrace alluvial boulder gravels. Upstream, the Río Llushín cuts exposures of red and purple shales, sandstones, and conglomerates of the Cretaceous Tena Formation (Baños geological sheet 88; Appendix B). The conglomerates are weakly-bedded and comprise rounded, (tens of cm. diameter) pebbles of massive, mesothermal vein quartz in a well-cemented to friable matrix of chalcedonic silica or silt respectively. A heavy mineral concentrate was panned from the conglomerate and yielded several fine gold colours. Alluvial gold is worked in terraces and active river gravels, and extensive alluvial terrace deposits are mapped along the lower reaches of the Río Llushín (Baños geological sheet 88; Appendix B).

Alluvial gold from river gravel comprises coarse (< 1 cm. dia.) to fine grains. Colour is deep yellow, and surfaces are finely-pitted and marked by deep dents and fractures. The grains are equant to elongate and flattened, but larger grains are quite thick. The grains comprise rounded to irregular nuggets and flat plates. No surface coatings were observed but one grain was partially amalgamated with mercury.

The alluvial gold in the Ríos Palora and Llushín is, likely, derived from mesothermal, shear zone-hosted quartz veins in the batholitic-metamorphic hinterland to the west (Cordillera Real). In the Río Llushín, a portion of the alluvial gold may be supplied by the auriferous quartz pebble conglomerates of the Cretaceous Tena Formation, but this gold also likely derived from mesothermal quartz veins.

2.1.10 Tena region (Figure 4b)

Numerous rivers in the Tena region are classified as auriferous, particularly the Río Napo and its tributaries the Ríos Jatunyacu, Verdeyacu, Chalupas/Cedro Yacu, Anzu, Ila, Piatua and Pano (Pillajo and Báez, 1983, Villavicencio, 1858; Chalupas geological sheet 86, San José de Poaló geological sheet 87, Tena geological sheet 101, Puerto Napo geological sheet 102; Appendix B). Many smaller tributaries within this drainage system are also auriferous, especially in the lower lying sub-Andean zone east of the Cordillera Real. In addition, the Tiyuyacu, Arajuno and Mera sedimentary rock Formations are said to be auriferous (Tena geological sheet 101). The catchment area of the Río Napo is large and drains the Cordillera Real between the Llanganates range in the south and the southern slopes of the volcano Antisana in the north.

The geology of the catchment area of the Río Napo comprises a complete section of lithologies across the Cordillera Real. From west to east these lithologies include Tertiary to recent volcanics of the inter-Andean graben; basaltic amphibolites (Monte Olivo subdivision), granite (Tres Lagunas subdivision), semipelitic quartzites and black phyllites (Chigüinda subdivision), and muscovite-garnet ± graphite schists, muscovite paragneiss and metapsammites (Agoyán subdivision), of the Loja division; deformed granodiorite and diorite porphyry (Azafrán subdivision), andesitic greenstones, volcaniclastics, greywackes and pelitic schists (Upano subdivision), and marbles and metasediments (Cerro Hermoso subdivision) of the Salado division; and relatively flat-lying outliers (klippen) of calcic-magnetite skarn and biotite megacrystic amphibolite. Eastwards, into the sub-Andean zone, the rivers cross Cretaceous sediments (Napo and Tena Formations), continental volcanics (Misahuallí Formation), and granite (Abitagua subdivision, Zamora division), before passing into the Tertiary and Quaternary sediments of the Oriente.

Structure in this region is complex and comprises Andean-trending foliation in the basement schists, and tectonic contacts (shear zone faults) between different lithotectonic subdivisions. Skarn and amphibolite klippen are characterised by relatively flat-lying foliations and thrust-faulted contacts. Cretaceous sediments in the sub-Andean zone are also thrust faulted.

Río Verde-Yacu: Within the Cordillera Real, at 1460 m altitude in the Río Verde Yacu, country rock comprises black, fine-grained shales or phyllites (Napo Formation). River boulders dominantly comprise black, bedded, fine grained sediments (Napo Formation), cut by massive, white calcite (± ankerite) veins; grey, silicified sediments (Napo Formation) with quartz (± disseminated pyrite) veins; and epidotized greenschists with granular (diorite?) and mylonitic fabrics. Other lithologies include grey, fine grained, psammitic (ortho-?) schist; granite (Tres Lagunas); feldspar-phyric dacite porphyry; maroon-purple-coloured, fine-grained, massive or vesicular, andesitic lava; a variety of light to dark-coloured, porphyritic and/or vesicular dacitic to andesitic lavas; and massive, mesothermal vein quartz (± ankerite ± chlorite ± pyrite ± pyrrhotite ± black or greenschist inclusions).

Gold was panned from boulder gravel alluvium at the river bank and yielded one or two colours per pan. Miners claim that alluvial gold in the Verde Yacu is fine grained and is not worked.

Río Chalupas (Cedro Yacu): West of the Río Verdeyacu, at 1425 m altitude in the Río Chalupas/Cedro Yacu, country rock comprises green/blue-purple-coloured, fine- to medium-grained, metavolcanic/volcaniclastic rock (Upano subdivision?). River boulders are dominated by green-coloured, metavolcanic/volcaniclastic rock (Upano subdivision?); and maroon-coloured, meta-volcaniclastic schists. Other lithologies include medium- to coarse-grained, granular leucogranite; coarse-grained, granular, epidotised, hornblende granodiorite; fine-to coarse-grained, greenschist; grey, fine-grained, mica schist; massive, homogeneous, grey-green and dark grey porphyries; coarse-grained, vesicular or weathered, volcaniclastic breccia; medium- to coarse-grained, dacitic-rhyolitic, welded tuff-breccia; black/purple-coloured, fine-grained, bedded sediments; and massive, white, mesothermal vein quartz (± greenschist/chlorite ± calcite inclusions).

Riverbed alluvium yielded up to 10 gold grains per pan and the river is reputed to be rich, however, few miners work this area because of its inaccessibility. The gold is deep golden-yellow, coarse to fine-grained (< 1 cm. dia.), and comprises thick, irregular to rounded plates and pellets with medium- to coarsely-pitted surfaces, sometimes coated with iron oxides. Bright yellow grains are often intergrown with quartz. One grain of dull silver-grey metal (platinum group metal, electrum or bismuth?) was noted.

Río Mulatos: Río Mulatos is one of the main tributaries of the Río Jatunyacu/Napo and drains the Llanganates range. Local miners claim that the Mulatos carries no gold, or not enough to warrant exploitation.

Río Jatunyacu: The Ríos Verdeyacu, Chalupas/Cedroyacu and Mulatos comprise the upper reaches of the Río Jatunyacu, itself the upper section (upstream of Puerto Napo) of the Río Napo. The Río Jatunyacu/Napo is auriferous.

Alluvial gold from the Río Jatunyacu is deep golden yellow, coarse- to fine-grained (< 1 cm. long), and comprises thin to moderately thick, irregular, elongate and discoid plates. Grain surfaces are medium- to coarsely-pitted and sometimes coated with iron oxide.

Alluvial gold from the Río Balsamo, a tributary of the Jatunyacu near Puerto Napo, is deep golden-yellow, medium- to fine-grained (< 7 mm. dia.), and comprises sub-rounded to angular, moderately thick, elongate, equant and irregular shaped plates. Grain surfaces are medium- to coarsely-pitted and, sometimes, coated with iron oxide.

At Sardinas, southeast of Shandia on the Río Jatunyacu, alluvial gold is worked from terrace alluvium and active river sediments. The terrace alluvium comprises boulders of medium- to coarse-grained granite; grey, medium- to fine-grained, porphyritic volcanics; fine- to medium-grained volcaniclastic rocks; fine-grained granodiorite; white-grey, massive, silicified (sedimentary?) rock with mesothermal quartz veins; semi-pelitic schist/meta granite; and massive, white, mesothermal vein quartz. Boulders are set in a clay gravel and the Formation is deeply weathered. The alluvium (Mera formation?) rests unconformably on red-green-beige-coloured, fine-grained sandstone (Tena Formation?).

Gold from riverbed alluvium is deep golden-yellow, medium- to fine-grained (< 8 mm. dia.), and comprises flat, thin to moderately thick, irregular and elongate plates and wires. Grain surfaces are medium- to coarsely-pitted and grains are sometimes intergrown with quartz. Gold from this locality is reputed to be coarse (up to 10 g nuggets), and two finely-pitted, discoid grains weighing about 0.4 g each were observed from terrace workings.

Río Anzu: Río Anzu and many of its tributaries are auriferous. The Río Anzu joins the Río Napo at Puerto Napo. Near the town of Arosemena Tola, river boulders in the Río Anzu comprise grey, fine- to medium-grained andesitic lavas and porphyries; and grey-white, medium- to coarse-grained, feldspar-phyric, granodiorite (Abitagua subdivision?). Other lithologies include pink/beige/ white-coloured, porphyritic volcanics; dark grey-coloured, fine-grained volcanics; pyroxene-phyric granodiorite; green, fine-grained, silicified and pyritized volcanics; and grey-white, massive, mesothermal vein quartz.

Alluvial gold from the Río Anzu is deep golden-yellow, medium- to fine-grained (< 8 mm. dia.), and comprises thick to thin, discoid, elongate and irregular plates and pellets, sometimes intergrown with quartz. Grain surfaces are fine- to coarsely-pitted.

Río Napo: Gold is worked from alluvial terraces and active river sediments along the Río Napo downstream of Puerto Napo. At Puerto Misahuallí gold is purchased by shop-owners.

The alluvial gold is bright golden-yellow, fine- to medium-grained (< 5 mm. dia.), and comprises thin, flat discs and irregular plates. Irregular-shaped grains are sometimes intergrown with quartz. Grain surfaces are fine- to coarsely- pitted and sometimes striated.

Tiyuyacu Formation: Bedded gravels of the Tiyuyacu Formation (Figure 4a, b, c) were examined south of Puerto Napo and southwest of Tena. These sediments comprise poorly lithified beds of purple-brown, coarse, quartzitic sands and gravels, dominated by well-rounded, well- sorted pebbles (cm. to tens of cm. diameter) of massive, white, mesothermal vein quartz, as well as grey, microcrystalline quartz and fine-grained grey mica schist. The Tiyuyacu sediments represent a high energy, but mature, sedimentary environment resulting from a previous erosional episode in the Cordillera Real in Eocene or Oligocene time (Sauer, 1965; Baldock, 1982). Gold, like the vein quartz pebbles, would have been concentrated as a resistate mineral, the former to be released subsequently on erosion of the sediments. The gravels of the Tiyuyacu Formation have lithological and sedimentological similarities to the quartz-tourmaline-gold pebble gravels of the Río Shincata area (Bestión Formation: Pillajo and Báez 1983; Jemielita, 1991b; Appendix F2), but are considered to be of different age. Nevertheless, the genetic processes involved in their formation were probably similar. The Tiyuyacu Formation and other sedimentary Formations in the sub-Andean zone (Tena, Arajuno, Mera, and Chambira Formations) are also auriferous (Pillajo and Báez, 1983; Tena geological sheet 101), and may be substantial or at least partial sources of the alluvial gold found in active river sediments in the Tena area.

Alluvial gold in the Tena area and Río Napo is, therefore, likely derived from at least two sources. Firstly, auriferous primary, mesothermal quartz veins cutting metamorphic and plutonic lithologies of the Cordillera Real and, secondly, gold from the (Eocene-Oligocene) Tiyuyacu Formation and (Cretaceous- Tertiary) Tena and other alluvial formations, previously derived from erosion of the Cordillera Real.

Río Topo: The Río Topo is a tributary of the Río Pastaza and is classified as being auriferous (Pillajo and Báez, 1983; Map 6d; Jemielita and Bolaños, 1992a; Appendix F6). The Río Topo flows east then south from the heart of the Llanganates range, draining lithologies of the Tres Lagunas, Agoyán, Cerro Hermoso, Azafrán and Upano subdivisions as well as calcic-magnetite skarn (Litherland et al., 1990).

Alluvial boulders and pebbles comprise granodiorite; mica schist (sometimes silicified); black siltstone/phyllite; porphyritic felsite and granite or monzonite; red-brown sandstone; and massive, mesothermal vein quartz.

The source of alluvial gold in the river may be attributed to mesothermal quartz veins, mineralization associated with granitoid and/or porphyry intrusions, and/or, possibly, skarn mineralization.

2.1.11 Cosanga - El Chaco (Figure 4c)

The Ríos Cosanga, Quijos, Oyacachi, Coca, Payamino, and some of their tributaries, are classified as auriferous (Pillajo and Báez, 1983; Baeza geological sheet 100, Appendix B). No alluvial mining was observed, but the richest river sections for alluvial gold are shown near Cosanga (Río Cosanga), El Chaco (Río Oyacachi), Sardinas (Río Coca), and San José de Payamino (Río Payamino; Pillajo and Báez, 1983). Only the latter two rivers are known to be exploited by local inhabitants.

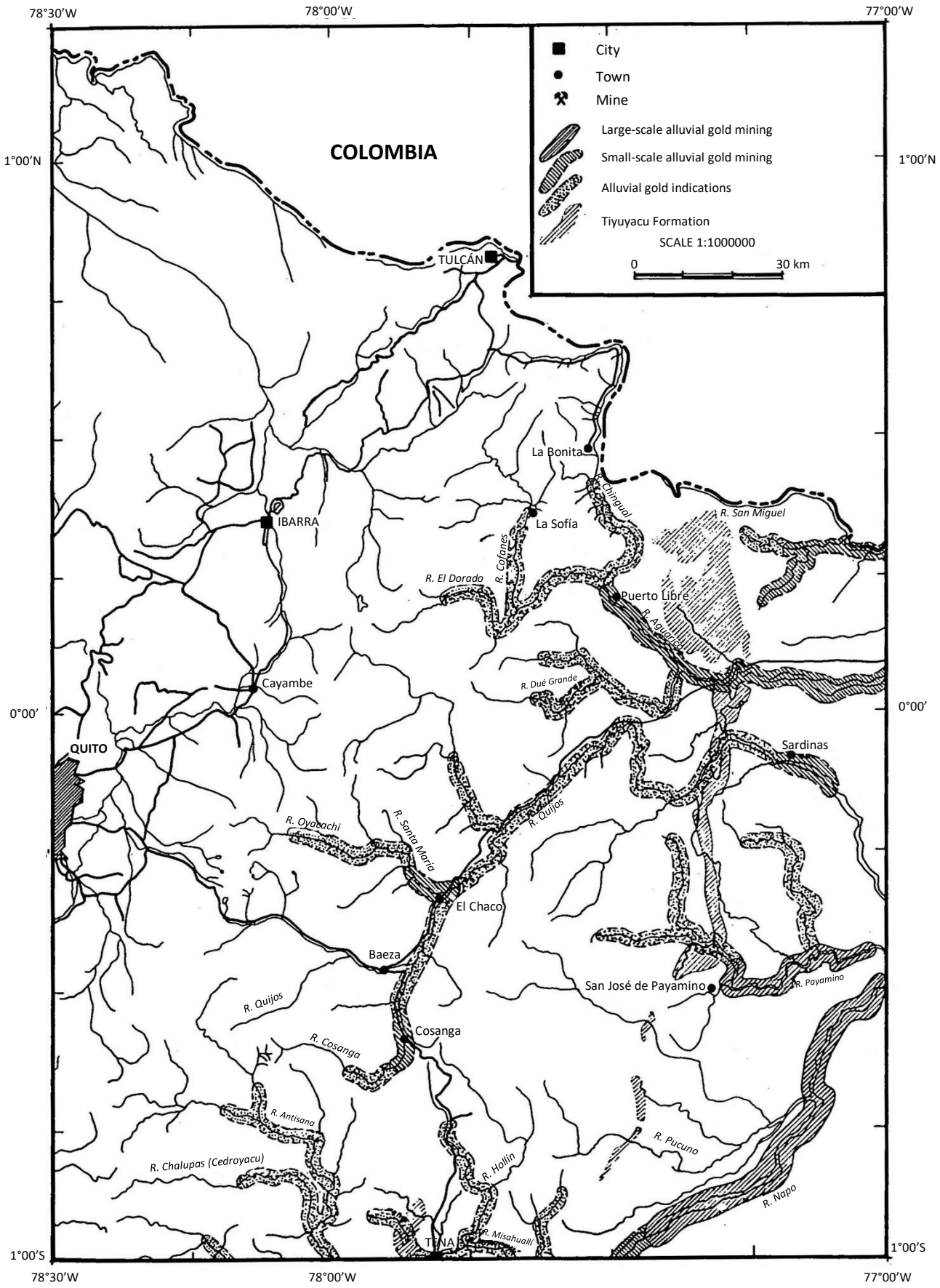

Figure 4c. Auriferous rivers in the north of the Cordillera Real

The Ríos Cosanga, Quijos, Oyacachi and their tributaries drain a large area of the northern Cordillera Real. The Ríos Cosanga and Oyacachi are tributaries of the Quijos which is known as the Río Coca downstream (in the sub-Andean zone). The geology of the catchment area comprises a complete section of lithologies across the Cordillera Real. From west to east these lithologies include Tertiary to Recent volcanics of the inter-Andean graben; basaltic amphibolites (Monte Olivo subdivision), granite (Tres Lagunas subdivision), semipelitic quartzites and black phyllites (Chigüinda subdivision), and muscovite-garnet ± graphite schists, muscovite paragneiss and metapsammites (Agoyán subdivision), of the Loja division; deformed granodiorite and diorite porphyry (Azafrán subdivision), andesitic greenstones, volcaniclastics, greywackes and pelitic and graphitic schists (Upano subdivision), and marbles and metasediments (Cerro Hermoso subdivision) of the Salado division; and relatively flat-lying outliers (klippen) of calcic-magnetite skarn and serpentinite. Eastwards, into the sub- Andean zone, the rivers cross Cretaceous sediments (Napo and Tena Formations), and continental volcanics (Misahuallí Formation), before passing into the Tertiary and Quaternary sediments of the Oriente.

The Río Payamino has no direct connection with the Cordillera Real and drains the eastern slopes of the volcano Sumaco and Cretaceous and younger sediments of the sub-Andean zone.

Structure in this area of the Cordillera Real is complex and comprises Andean-trending schistosity in the basement schists, and tectonic contacts (shear zones) between, and within, different lithological subdivisions. Skarn and serpentinite klippen are characterised by relatively flat-lying foliations and thrust-faulted contacts. Cretaceous sediments in the sub-Andean zone are also thrust faulted.

Río Cosanga: In the vicinity of Cosanga and upstream (Map 6b; Jemielita and Bolaños, 1992a; Appendix F6), alluvial boulders in the Río Cosanga comprise medium-grained, granular, porphyritic or vesicular, grey and maroon-coloured volcanic rocks; grey-green-black mica schists; granodiorite; massive, mesothermal vein quartz (± calcite); augen schist; black slate; brown-green siltstones; and dark green, massive serpentinite. One or two very fine gold colours were observed in heavy mineral pan concentrates from the Río Cosanga.

Río Oyacachi: In the lower reaches of the Río Oyacachi, at the junction with the Río Santamaría and downstream (Map 6a; Jemielita and Bolaños, 1992a; Appendix F6), alluvial boulders comprise a variety of mylonitized greenschists and epidotites; sheared porphyry; (Tres Lagunas) granite; granodiorite; and maroon-coloured, fine-grained mica schist. Massive, mesothermal vein quartz is common, and frequently carries massive calcite, fine-grained chlorite and masses of pyrite and/or chalcopyrite. In the Río Santamaría, iron-stained boulders of white-grey-green, fine- to medium-grained, sericite chlorite schist with disseminated pyrite and chalcopyrite, are common. Gold was not observed in heavy mineral pan concentrates but the Río Oyacachi is classified as auriferous (Pillajo and Báez, 1983).

The source of alluvial gold in these rivers is probably mesothermal quartz veins which cut the basement schist lithologies of the Cordillera Real. The Ríos Coca and Payamino probably also obtain gold from the Eocene Tiyuyacu Formation quartz pebble conglomerates, and it is noteworthy that the richest parts of these rivers occur immediately downstream of their intersection with this formation. Furthermore, the auriferous Río Payamino has no direct connection with the Cordillera Real, therefore the Tiyuyacu Formation sediments are, likely, the dominant or sole source for the alluvial gold. The ultimate source of the gold in the Tiyuyacu Formation was also (now eroded) mesothermal quartz veins in the Cordillera Real.

2.1.12 La Sofia - Río Cofanes (Figure 4c)

The northernmost part of the Cordillera Real has few auriferous rivers but the Río Cofanes is worked for gold (Map 7d; Jemielita and Bolaños, 1992b; Mariano Acosta geological sheet 98, Appendices B and F7), and the tributary Ríos Dorado and Chingual are also classified as auriferous (Pillajo and Báez, 1983). These rivers unite to form the auriferous Río Aguarico. Immediately to the north of the Aguarico the Río San Miguel, which marks the frontier between Ecuador and Colombia, is also auriferous.

The geology of the catchment area of the Río Aguarico and its tributaries is dominated by plutonic granitoids of the Azafrán subdivision (deformed granodiorite and diorite porphyry and undeformed, leucocratic granite), and the Abitagua subdivision (deformed granodiorite, quartz syenite and monzonite). Other lithologies in the area include muscovite-garnet ± graphite schists, and muscovite paragneiss (Agoyán subdivision); fine biotite ± hornblende gneiss (Santa Bárbara subdivision); continental volcanics and fine siliceous rocks (Misahuallí subdivision); and, to the east, Cretaceous sedimentary rocks (Hollín and Napo Formations).

Structure is dominated by the Andean-trending foliation of the basement lithologies and tectonic (shear zone) contacts separating different basement subdivisions. The Cosanga fault marks the eastern boundary of the Cordillera Real and the La Sofia fault bounds the eastern contact of the Condué granite. In the La Bonita-La Sofia area, non-Andean-trending structures represented by foliation, mineral lineations, fractures and vein and dyke orientations, trend between N 84° E and N 110° E and dip from vertical to 75° N. These orientations have not been previously recognized and their significance is not understood at present. In the sub-Andean zone, thrust faulting affects the Cretaceous and younger sedimentary lithologies.

Río Cofanes: River boulders in the Río Cofanes generally reflect the granitoid-dominated composition of the basement lithologies. Other common boulders comprise white-grey-black-coloured, finely bedded, sulphide-mineralized (pyrite, chalcopyrite, pyrrhotite), hornfelsed sediment; mica schist; greenschist or amphibolite; and massive, white, mesothermal vein quartz. Mineralized river boulders in the La Sofia area comprise sulphide-rich, banded and hornfelsed sediments, and schists; sulphide-rich polymetallic vein quartz; and massive, mesothermal quartz veins. One local miner also had samples of sulphide-rich vein material consisting of massive white milky quartz and cream coloured dolomite or ankerite, with coarse pyrite, chalcopyrite and sphalerite, and a purple-grey, metallic (copper) sulphosalt. Similar material was seen with green, malachite-stained covellite and a dull grey, platey, metallic mineral, possibly chalcocite.

Local people claim that gold is panned from the Río Cofanes by up to thirty miners, mostly from sites downstream of the tributary Río Chalares. A small sample of this alluvial gold was obtained and is deep yellow in colour forming fine- to medium-grained, irregular- to rounded-discs, pellets and rods with coarsely-pitted surfaces. Nuggets of 30 g weight are said to have been found.

The source of the alluvial gold in the Río Cofanes is not known, but may be related to the observed sulphide-mineralized lithologies. The widespread occurrence of indurated/hornfelsed and sulphide-mineralized, banded sediments in the area, and to the east in the Rosa Florida area, indicates the probable existence of a sedimentary roof pendant above the (La Bonita) granodiorite and located along the intervening ridge. This situation is similar to the geological environment in the Zamora batholith, and the area should be investigated for potential skarn-related mineralization (see Gold-primary mineralization section).

Río Aguarico - Río San Miguel: In the sub-Andean zone, and eastwards into the Oriente, alluvial gold is worked in the Ríos Aguarico and San Miguel (on the frontier with Colombia) and some of their tributaries (Pillajo and Báez, 1983). Both rivers appear to be most gold-rich downstream of exposures of the Tiyuyacu Formation sediments and it is likely that this Formation is the source of much of the alluvial gold in these rivers. The Río Aguarico also probably obtains gold from the Río Cofanes river system.

2.2 Gold - Paleoplacer deposits

In the Sub-Andean zone, east of the Cordillera Real, gold occurs within Cretaceous and Tertiary sedimentary Formations and in river terraces and alluvium. The auriferous Tiyuyacu Formation is of particular interest because it occurs along a strike length of 150 km and 100 km respectively in the northern and southern areas of the sub-Andean zone (Figure 4a, b, c; see Gold-Alluvial Deposits; Tena Region). The Tiyuyacu Formation (vein) quartz pebble conglomerates have features in common with productive auriferous conglomerates in other parts of the world and of different ages (Pretorius, 1981).

2.3 Summary: Gold - Alluvial deposits

The common occurrence of massive, mesothermal vein quartz as river boulders in the Cordillera Real and adjacent areas, as well as comprising pebbles in the auriferous Tiyuyacu, Mera, Bestión and other alluvial formation sediments, suggests that alluvial gold originated from mesothermal, shear zone-hosted, quartz veins cutting the Cordillera Real basement lithologies. Few analyses have been published for alluvial gold from the Cordillera Real (Wolf, 1892; Beddoe-Stephens, 1987, 1989), but the results are broadly consistent with a mesothermal vein origin. Some results, however, support alternative origins for alluvial gold in places.

Wolf (1892) published analyses for alluvial gold samples from the Ríos Shincata (Bestión; 895 fine), Ayllón (843 fine), San Francisco (911 fine), and Collay (822 fine). Sub-Andean zone rivers have yielded alluvial gold fineness values of between 782 and 976 (one grain 553 fine; Beddoe-Stephens, 1987). The above gold fineness values mostly fall between 782 and 976 and are within the ranges of mesothermal quartz veins (Archaean and slate belt), plutonic, porphyry-related and epithermal mineralization (Morrison et al., 1991).

Beddoe-Stephens (1987, 1989) detailed silver contents in alluvial gold samples from the Cordillera Real e.g. Río Ayllón (Ave. Au 827 fine; 4-22 % Ag), Río Collay-Pilares (Ave. Au 813 fine; 5-25 % Ag), Río Santa Bárbara-Mina Peggy (Ave. Au 844 fine; 8-24 % Ag), Río de la Burra Playa-Principal (Ave. Au 879 fine; 5- 24 % Ag), Los Planes (Ave. Au 689 fine; 22-42 % Ag), and Piuntza (Ave. Au 798 fine; 16-28 % Ag). Average fineness values lie in the range 689 to 879. The high silver values of some of these samples suggest epithermal, volcanogenic or porphyry-related sources for silver-rich alluvial gold and there is geological evidence to support this e.g. epithermal mineralization at Los Planes and Piuntza (Clarke, 1989).

A more complete set of Cordillera Real alluvial gold samples has now been collected and will be analysed in the near future.

3. PRECIOUS METALS - PRIMARY MINERALIZATION

3.1 Gold

Estimated gold production figures for Ecuador in the years 1988 to 1992 are in the range of 10 to 13 tonnes per annum (unpublished INEMIN internal report; Figure 5). About 10 % of this production is from alluvial deposits and the remainder from "hard-rock" mines. Gold production in the Cordillera Real is presently dominated by alluvial mining, but considerable potential exists for the discovery and exploitation of primary gold deposits. In contrast, the rich primary gold deposits of the Zamora batholith (Cordillera de Tzunantza), in the southeast of Ecuador, currently yield the major proportion of gold production in the country (Figure 5).

This section will deal with occurrences of, and potential for, primary gold and silver mineralization in the Cordillera Real and Zamora batholith, classified genetically. Following this, structures and then young intrusions controlling gold and silver mineralization will be described.

3.1.1 Auriferous volcanogenic massive sulphide mineralization

Mina Pilas: Values of up to 479 ppb Au have been obtained from samples of massive, bedded pyrite from Mina Pilas (Appendix D). Mina Pilas is located about 16 km north-northeast of the village of Alao on the eastern slopes of the Cordillera de Pilas (Map 1; Jemielita, 1991a; Appendix F1), at an altitude of between 4155 and 4185 metres. Country rocks comprise greenschist and sericite schist meta-volcanic rocks of the Alao-Paute subdivision. Mineralization comprises massive, granular, bedded pyrite, interbedded with granular quartz and sericite schist horizons, enveloped in a footwall of pyrite-bearing sericite schist and a hanging wall of green chloritic schist, also with disseminated pyrite. The pyrite bed is at least 7 metres thick and about 200 metres long and is folded, with green chloritic schist in the core and white sericite schist in the envelope. The fold closes to the south and its axial plane dips steeply west. The thickness of the sericite schist is undetermined but exceeds tens of metres. Locally, foliation trends N173°E, dipping 74°W, but bedding in the pyritic horizon mimics the geometry of the fold. The pyrite horizon is cut in places by small epigenetic quartz veins and a dyke or vein of granular pyrite was observed intruding the sericite schist footwall. Both the sericite schist and chlorite schist exhibit strong and complex folding.

This deposit is a volcanogenic massive sulphide and is an encouraging indication for potential polymetallic copper-zinc-lead ± Au ± Ag mineralization in the vicinity, and elsewhere within the Alao-Paute subdivision.

Guarumales: Located within lithologies of the Upano subdivision, samples from the Guarumales polymetallic volcanogenic massive sulphide prospect (Map 4b) yielded up to 2510 ppb (2.5 g/T) Au in association with high values of Ag, Cu, Pb, Zn and other metals (see Cu, Pb, Zn section; Appendix D).

3.1.2 Volcanic-hosted epithermal gold mineralization

Anomalous gold values are frequently obtained from epithermal-style mineralization in young Tertiary to recent volcanic and volcanoclastic lithologies of the inter-Andean graben which lap onto the Cordillera Real basement. This is particularly evident along the Las Aradas-Baños fault where the former lithologies sometimes host auriferous (but usually silver-rich) epithermal mines (e.g. San Bartolomé, Pilzhum; see Silver section), and prospects. Epithermal mineralization is also encountered within the Zamora batholith and overlying areas of rhyolitic to andesitic volcanic and volcaniclastic rocks.

Gima-Cerro Colorado: An acid leached, silicified, gossanous porphyry breccia at Cerro Colorado east of Gima (Map 3a) assays up to 4259 ppb Au (Appendix D). Mineralization in the area comprises narrow, epithermal veins which cut the basement schists of the Tres Lagunas subdivision, and form wider zones of silicification within the overlying dacitic volcanic and volcaniclastic lithologies. Gold and silver values in the silicified zones are accompanied by anomalous As and Sb.

Cuchil: At Satunsaray, located east and uphill of the pueblo of Cuchil, about 4 km SSW of the pueblo of Sigsig (Map 4a; Jemielita and Bolaños, 1991a; Appendix F4), Au values of up to 4013 ppb (4 g/T) have been obtained (Appendix D) from a chalcedonic breccia. Geology comprises Quaternary volcanic lavas and tuffs (Tarqui Formation?) and, in the area examined, these rocks are exposed for about 150 metres along the east side of the Sigsig-Chigüinda road. Numerous float blocks are also scattered along the road margins and in nearby fields. The rocks comprise variously silicified, clay-altered and/or brown, iron oxide-stained, porphyritic, rhyolite lava flows and breccias. The breccias are sometimes polymict in composition and often have vugs containing fine-grained silica or alunite. At the north end of the roadside exposure a red-brown-stained, vuggy, grey, silicified, rhyolite porphyry breccia with disseminated pyrite forms a bed, overlain by cream-white-coloured, rhyolite breccia. Some of the breccias are composed of low-density opaline or chalcedonic silica. The silicified and sulphide mineralized nature of these rhyolitic lithologies strongly suggest epithermal-type mineralization which is frequently associated with rhyolite volcanism (White and Hedenquist, 1991) and, occasionally, with gold-silver and base metals mineralization. Similar rhyolitic lithologies were observed in the outcrops west of Cuchil and the entire area underlain by Quaternary (Tarqui Formation?) volcanics could have potential for economic epithermal mineralization.

Sigsig-Loma Quipal: Au (and Cu) assay values have been obtained Loma Quipal, located 1 km southeast of Sigsig (Pers. Comm. Alan Carter, 1992; Map 4a). Geology comprises andesite-dacite volcanic and volcaniclastic lithologies overlying sheared (Tres Lagunas granite) basement. Alteration and mineralization comprise weakly- to moderately-silicified and, sometimes, argillically-altered andesites/dacites, with disseminated pyrite in places. Blocks of porous and gossanous, acid-leached volcanics with hematite, jarosite, quartz and alunite are present, occasionally stained by copper sulphate. This epithermal mineralization may be connected with the porphyry-related mineralization around Mina Peggy.

San Bartolomé: Accessory values of gold are reported for the San Bartolomé epithermal silver mine near Cuenca (INEMIN-Misión Belga, 1988; see Silver section).

Pilzhum: Ore grades of 3.2 g/T Au are reported, together with silver (1500 g/T) and copper (2 %), for the Pilzhum epithermal silver deposit near Azogues (INEMIN-Misión Belga, 1988).

Osogochi-Atillo: Au values of up to 64 ppm have been recorded (Appendix D) from mineralized and altered volcanic lithologies from the Osogochi and Atillo areas, located about 45 km SSE of the town of Guamote, on the watershed of the Cordillera Real (Map 5b; Jemielita and Bolaños, 1991b; Appendix F5). Local geology is dominated by recent lavas and volcanoclastic rocks to the west which unconformably overly extensively, and often intensively, quartz-veined basement black schists and quartzites of the Maguazo subdivision, and greenschists of the Alao-Paute subdivision to the east. A prominent rocky mountain with red-coloured talus slopes, named Cerro Pucurcu Grande (Quechua equivalent of Cerro Colorado or Red Mountain), dominates the area west of Cerro Soroche (Map 5b). The red colour is due to iron oxide staining of the disseminated pyrite-bearing, feldspar-phyric porphyry of which the mountain is composed. Away from the most mineralized outcrop (about 3 km^2 in area) at Cerro Pucurcu Grande, the country rocks comprise medium-grained, grey, porphyritic andesites, sometimes with epidote (propylitic) alteration. This lithology contains small areas of more intense alteration and mineralization in places. Other areas of relatively extensive and intensive hydrothermal alteration and mineralization include the northwest slopes of Cerro Tintillay (Map 5b). A narrow valley here contains yellow-brown-coloured scree comprising white-grey, altered and silicified andesite porphyry and breccia with fine- to medium-grained disseminated pyrite and rarer chalcopyrite. The quebrada downhill from this site contains a coarse alluvial/colluvial sediment of altered and mineralized porphyry in a clay matrix. Pan concentrates of this material comprise almost pure pyrite sand.

Other areas of hydrothermally altered and sulphide mineralized porphyry volcanic rocks occur at mountain 4.060 to the west of Laguna Verde Cocha, in the vicinity of the lower reaches of the quebrada Yuracyacu (Map 5b), and in the vicinity of the village of Atillo.

Most of the lithologies described above are probably lava flows and volcaniclastic rocks but some exposures may be intrusions or intrusive breccias. Cerro Pucurcu Grande is considered to be particularly important because it comprises a large area of mineralized porphyry. In addition, a Cerro Pucurcu Chico is marked on the topographic map (Huangra 1:50000 scale; Appendix A) about 3 km SSW of Cerro Pucurcu Grande, and is probably of similar composition. Economic potential is suggested by the existence of a quebrada de Minas on the eastern side of Cerro Pucurcu Chico (Map 5b). Local guides suggest that this quebrada is auriferous. It is likely that the extensive hydrothermal alteration and mineralization associated with these porphyritic lithologies is related to high-level porphyry intrusions.

Zamora Batholith: Important porphyry-related polymetallic, epithermal vein, intrusive breccia, and disseminated gold-silver mineralization occurs in association with young (Tertiary?) porphyritic dacite-rhyolite intrusions and volcanic/volcaniclastic rocks at numerous localities in the Zamora batholith e.g. Chinapintza, Piuntza, Los Planes (Clarke, 1989; Gemuts et al., 1992; Figure 6).

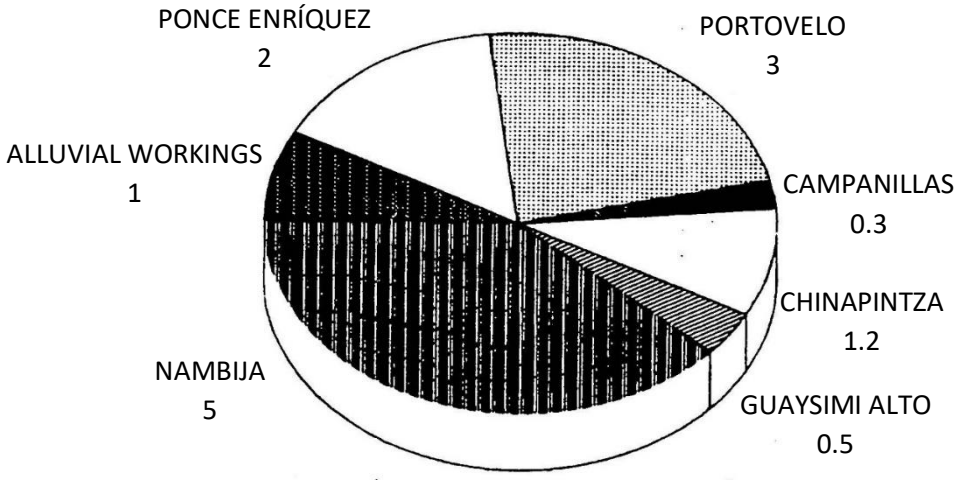

Figure 5. Diagram of approximate gold production of Ecuador in 1990 (INEMIN-CODIGEM).

Chinapintza: In the Chinapintza mining area of southeast Ecuador (Figure 6) a suite of polymetallic (Cu-Pb-Zn bearing), epithermal quartz veins (< 0.5 m wide) are hosted by coarse-grained granodiorite (Zamora Batholith?), tuffs and feldspar porphyries. Values of up to 363 g/T gold have been obtained from grab samples (Clarke, 1989), but average grade is estimated at about 50 g/T Au (Gemuts et al., 1992). The Viche (or Biche) prospect, located 2.5 km south of Chinapintza, comprises sulphide-mineralized diatremes and intrusive breccia pipes cutting sulphide-rich (pyrite and sphalerite), silicified and quartz-veined, dacite-rhyolite tuffs and lava flows. Mineralized samples yield up to 10.9 g/T Au, and average 1.5 to 2 g/T Au (Gemuts et al., 1992).

Piuntza: The Piuntza prospect located 13 km west of Nambija (Figure 6). Gold mineralization is associated with a central (intrusive?) breccia and a network of quartz-sulphide veinlets cutting a quartz-feldspar porphyry plug. The prospect is located within the remains of a volcanic and volcaniclastic pile. Pyrite and sphalerite are reported, as well as gold (up to 7.32 g/t) and silver (up to 38 g/t; Clarke 1989). The description of Piuntza closely resembles that of the Viche area south of Chinapintza.

Los Planes: The Los Planes epithermal gold-silver prospect is located southeast of Zumba and consists of a series of narrow quartz veins and quartz stockworks hosted by strongly weathered and argillized tuffs and dense andesite lavas which overlie the Zamora batholith. A sample of dense quartz stockwork assayed 233 g/T Au but other samples ranged from 3.02 g/T to below detection (Clarke, 1989).

3.1.3 Porphyry-related gold mineralization

Fierro Urcu: Fierro Urcu is a (porphyry-related) copper- molybdenum and precious metals (vein) prospect, located 14 km SW of Saraguro on the western flank of the Cordillera Real (see Cu, Zn, Pb section; Loja geological sheet 56; Appendix B). Abandoned adits in the area follow polymetallic veins, exploited in colonial times for gold and silver. Country rocks are Tertiary (Oligocene?) andesitic to rhyolitic volcanic and volcaniclastic lithologies intruded by dykes and plugs of granodiorite and, possibly, underlain by lithologies of the Alao-Paute subdivision. The veins comprise milky quartz with tourmaline, pyrite, chalcopyrite, molybdenite, and traces of enargite, stibnite and other sulphides. Gold assay values of up to 22 g/T (most values below 1 g/T) have been obtained for vein samples, and an estimate of 53.5 million T of mineralized rock containing 0.3 ppm Au (and 0.2 % Cu) has been made based on drilling, probably in porphyry- style disseminated mineralization (INEMIN-Misión Belga, 1988).

Saraguro-Lomo del Loro: Six km SSW of Saraguro, a recent roadcut at Lomo del Loro exposes extensive argillically-altered dacite porphyry at Lomo del Loro (Map 2f; Jemielita, 1991b; Appendix F2). Gold values of up to 822 ppb (Appendix D) have been obtained from sulphide mineralized, clast-supported, dacite porphyry intrusive breccia within a quartz-feldspar-phyric dacite pluton. Small-scale artisanal mining in the area exploits argillically-altered dacite porphyry breccia containing pyrite, arsenopyrite, chalcopyrite and sphalerite. A nearby intrusive breccia, east of Cerro Puglla (Map 2f), assays up to 217 ppb Au (Appendix D), and is characterized by silicified and pyritized porphyry clasts, sometimes with pink, crystalline alunite.

Sigsig-Mina Peggy: Porphyry-related, polymetallic mineralization at Mina Peggy near Sigsig (Map 2h; Jemielita, 1991a, b; Appendices F1 and F2; see Cu, Pb, Zn, section) yields gold values up to 2660 ppb Au, but is dominated by silver (Appendix D).

Ayllón-Santa Bárbara: East of Mina Peggy in the vicinity of the confluence of the Río Santa Bárbara and the Río Ayllón (Map 4a; Jemielita and Bolaños, 1991a; Appendix F4), quartz- arsenopyrite (± other sulphides; see Gold - Alluvial Deposits section) boulders in the rivers assay up to 5.2 ppm Au. In the same area, a quartz vein containing arsenopyrite, pyrite and other sulphides has been mined approximately 0.5 km downstream of the junction on the east bank of the Río Santa Bárbara. This site was previously examined by Clarke (1989) who reported gold values of 46.5 to 635 g/T for ore samples from the dump, and these values have been confirmed (Appendix D). About 1 km upstream of the junction on the east and, particularly, the west banks of the Río Ayllón, hard rock workings were observed producing gold from a 0.5-metre-thick quartz-pyrite-chalcopyrite-arsenopyrite (and other sulphides?) vein which intrudes the basement schists (Chigüinda subdivision) with a trend of N67°E, dipping 68°NW. This vein mineralization may be a gold-rich distal zone (Jones, 1992) related to the Mina Peggy porphyry-related mineralization. The Ayllón area is presently (Jan 1993) the target of a minor gold rush for alluvial and hard rock gold (A. Hirtz, pers. comm., 1993).

Zamora Batholith: Potentially gold-bearing porphyry prospects are documented in the Zamora batholith area at Hito near Chinapintza, and Cutuntza, and Augusta near Nambija (Gemuts, 1992).

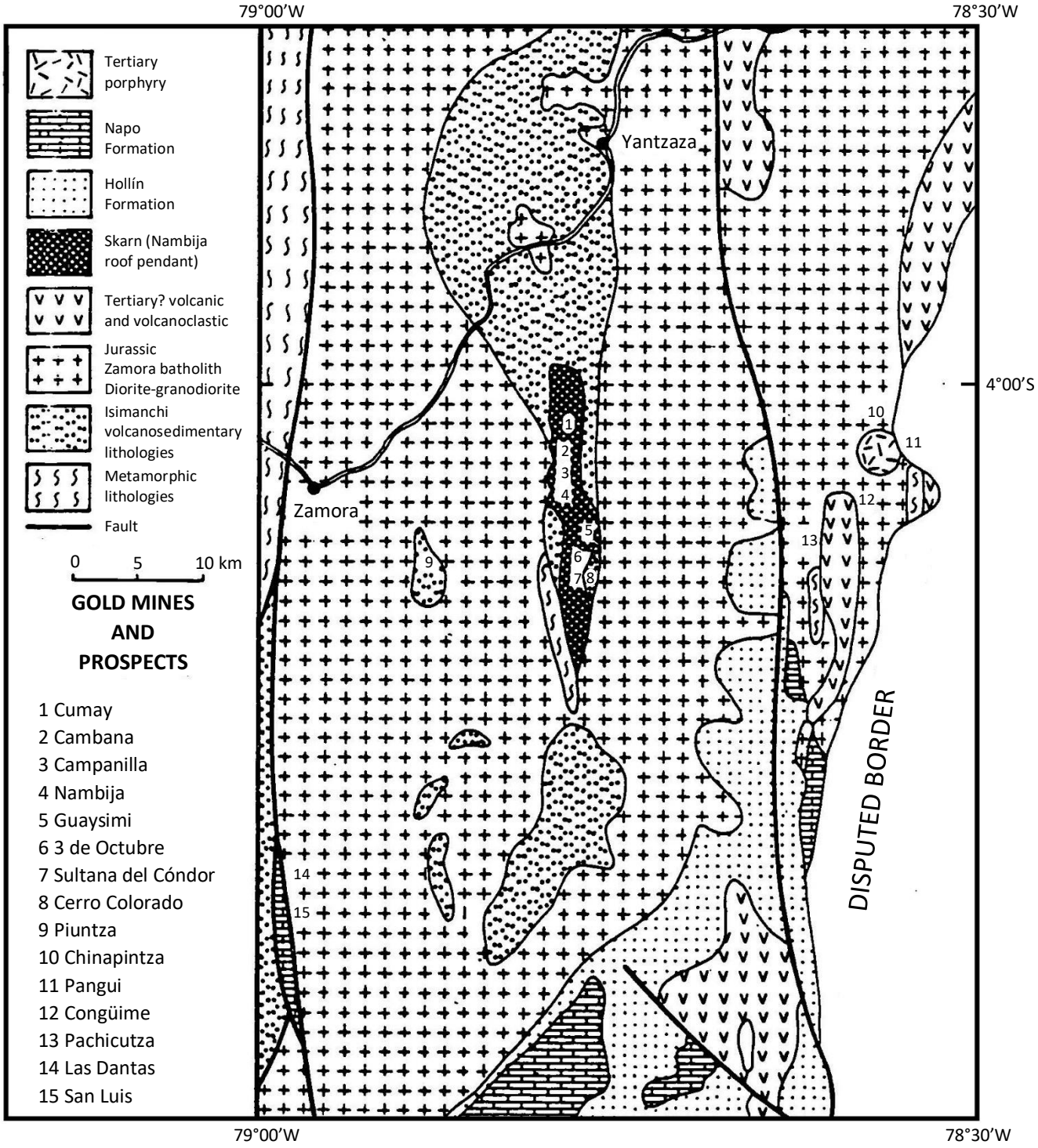

Figure 6. General geology and location of gold mines and prospects of the Zamora Batholith (after Litherland et al. in prep.).

3.1.4 Gold-skarn mineralization

Some of the most important occurrences of gold mineralization in Ecuador are located in lithologies of the Isimanchi subdivision where they form roof pendants within the Zamora granodiorite batholith (Abitagua subdivision; Figure 2). The auriferous Nambija mining district was exploited during early Spanish colonial times and, possibly, in Pre-Colombian times (Navarro, 1986), and was rediscovered in 1981. The area has since become the most productive gold mining area in Ecuador. The rediscovery of Nambija has stimulated exploration and mining over large areas in SE Ecuador and many gold-producing areas now exist (Figure 6; Gemuts et al., 1992). Mining is still, however, dominated by artisanal techniques as practiced by individual and cooperatives.

The area from Zamora east to the disputed border with Peru, and north from the same border to west of the town of Gualaquiza, is underlain by the regional scale Jurassic (190 Ma), calc-alkaline, granodiorite-diorite Zamora batholith (Figure 2). In places, the batholith hosts large inclusions, interpreted as roof pendants (Litherland et al., 1990), comprising a sequence of marbles, sandstones, andesitic-dacitic lavas and volcaniclastics which are thought to belong to the upper Triassic Isimanchi subdivision.

Nambija: The Nambija district is located 19 km east of the town of Zamora (Figure 6). The topographic map (Zamora 1:50000 scale sheet; Appendix A) shows old workings in the area, as well as small rivers (quebradas) named Oro (gold) and Fierro and Hierro (iron i.e. probably after magnetite blocks found commonly in the rivers; see Iron section). In the Nambija district, and other locations within the roof pendant, the volcano-sedimentary protolith is skarnified. The skarn areas often correspond with mining districts (Figure 6). At the Campanillas mine, and southwards in the Nambija township area, the sedimentary sequence is well exposed in mine workings.

The following petrographic description is taken from Litherland et al. (in prep.).

Skarns at Nambija vary from virtually monomineralic grandite rocks to incipiently skarnified protolith, predominantly comprising andesitic volcaniclastics (tuffs/breccias) that exhibit sericitic and propylitic (chlorite, epidote, prehnite) alteration. Retrogressive calcite-quartz-chlorite-K feldspar alteration is found in the Nambija skarn. Specimens examined vary from fresh garnet-rich rock lacking this late paragenesis, to material in which both early and late garnet are extensively replaced. Deposition of pyrite occurred at this late stage, and current indications are that gold was also deposited principally during the retrograde alteration, rather than during initial formation of the garnetiferous paragenesis.

A striking feature of the Nambija rock as seen in thin section is the clear, unstrained, poikilitic habit of the quartz, giving the superficial appearance of being unaffected by alteration processes. Fluid inclusion homogenisation temperatures from this quartz (Shepherd, 1988) indicate formation or recrystallisation and annealing at relatively low temperatures of about 200°C. Moreover, a pattern in which fluid temperature decreased to around 150°C, and salinity increased from ca. 2 to 24 weight % NaCl equivalent, is indicated by comparison of fluid inclusion data for quartz from, apparently, unretrogressed garnet skarn with that for quartz in auriferous, carbonate-adularia-bearing rock. Retrograde alteration evidently commenced with regrowth and annealing of interstitial quartz before introduction of carbonate and associated minerals.

On a regional scale, mineralization in the Nambija roof pendant appears to be controlled by two parallel and regional scale N-S trending faults.

On a mine scale, mineralization is localised along a set of NE-trending brittle fractures. The latter fractures control both skarnification and economic gold mineralization. The mineralized structures are sub-vertical and cut a layer-cake stratigraphy. The extent of skarnification within individual layers varies, being wider in the fine-grained tuffs and narrower in the breccias. This difference is attributed to variations in rock chemistry and, possibly, permeability.

The skarns at Nambija form a significant gold deposit with grades up to 200 g/t in the richest pockets, but averaging 15 g/t. Production has been estimated at 3 to 6 tonnes per annum (Gemuts et al., 1992; Figure 5), and ore reserves of the order of millions of tonnes have been estimated (Salazar, 1988). Assay data from Nambija samples indicates a Au:Ag ratio of ca. 20:1 (Clarke, 1989), which is comparable to Au:Ag ratios in the analysed native gold (see below) and higher than the gold skarn ratios quoted in Meinert (1988). This is in contrast to the Au:Ag ratios of ca. 1:10 recorded in non-skarn (epithermal) deposits such as at Chinapintza and Piuntza prospects (Clarke, 1989; Figure 6). Native gold, where observed, forms blebs up to 1mm across associated with K-feldspar, calcite and quartz, and interstitial to grandite. The composition of this gold measured by EPMA varies from 3 to 13 atom. % Ag (Beddoe-Stephens, 1987 and 1989). Pyrite and chalcopyrite occur in these skarns.

In summary, the Nambija roof pendant comprises a N-S elongated exposure of Triassic volcanic and sedimentary rocks forming a recognizable stratigraphic sequence underlain by granodiorites and diorites of the Jurassic Zamora batholith. The roof pendant lithologies are intruded, in places, by later basic dykes and monzonite porphyry dykes and plugs (pers. comm., A. Rogers, 1991). Two regional scale N-S orientated faults control the locations of mining districts but on a mine scale NE structures control skarnification and gold mineralization. Mineralization is dominated by gold but significant showings of copper have been observed at Campanillas and other metals are present. The Nambija deposits are regarded as being gold-dominated porphyry related skarns.

Other mine camps within the Zamora batholith (Nambija) volcano-sedimentary roof pendant exploit gold skarns e.g. Cumay, Cambana, Campanilla, Guaysimi, 3 de Octubre, and Sultana del Cóndor (Figure 6).

Litherland et al. (1990) report gold values of up to 15 ppm for samples from the northern skarnfields of the Cordillera Real but this has not been confirmed.

3.1.5 Granodiorite intrusion-related gold mineralization

Quebrada Quishpe-Alao: In the quebrada Quishpe area, southeast of Riobamba (Map 1; Jemielita, 1991a; Appendix F1), lithologies of the Cebadas subdivision (Guamote division) are intruded by a granodiorite pluton which hosts auriferous polymetallic vein mineralization. Free gold occurs locally in soils and streams (see Gold - Alluvial Deposits section).

Río Ishpingo: In the Río Ishpingo area (Map 4a; Jemielita and Bolaños, 1991a; Appendix F4), a sulphide-mineralized, biotite granodiorite intruding Chigüinda subdivision schists yielded up to 319 ppb Au (Appendix D).

Río Isimanchi: In the upper reaches of the Río Isimanchi, located in the south of Ecuador on the frontier with Peru (Map 2a; Jemielita, 1991b; Appendix F2), a value of 171 ppb Au was obtained for a pyrite-mineralized breccia vein cutting granodiorite of the Portachuela batholith (Appendix D). The Portachuela batholith intrudes basement lithologies of the Chigüinda and Sabanilla subdivisions.

3.1.6 Mesothermal quartz gold vein mineralization

Cera-Loja: At Cera, about 15 km NW of Loja, gold has been mined from narrow, quartz-ankerite-pyrite veins hosted within sheared black and grey schists of the Agoyán subdivision. To the east of Loja, Wolf (1892) describes similar mineralization at Cerritos de Calvario.

Masanamaca: At Masanamaca, between the villages of Vilcabamba and Yangana, gold has been worked from quartz veins in black and grey schists (Chigüinda subdivision) along the Río Minas (Wolf, 1892; Bonilla, 1987). A mine was visited in similar geological environment along the Río Chiriguana, east of Yangana (Map 2c; Jemielita, 1991b; Appendix F2).

Guamote: The Guamote division is best exposed between Riobamba and Achupallas and comprises black slates and quartzites (Guasuntos and Cebadas subdivisions), and black and pale quartzites with slates (Punín subdivision). Although no gold mineralization has been recorded in these lithologies they are mentioned here because they commonly contain massive, brittle and ductile-type, mesothermal quartz veins which can be auriferous.

The widespread occurrence of massive, mesothermal vein quartz as boulders and pebbles in often auriferous rivers and terrace alluvium and sedimentary formations strongly suggests that much of the alluvial gold of the Cordillera Real derived from mesothermal vein quartz mineralization.

3.1.7 Miscellaneous gold mineralization

Litherland et al. (1990) report traces of gold and silver in samples from the Peltetec ophiolitic and Maguazo turbiditic sedimentary subdivisions, but these reports have not been confirmed.

The Mina Curiayana is located on the ridge separating Quebrada Minas and Quebrada Shiga 3.6 km to the east-north of the pueblo of Alao at an altitude of 4155 metres (Map 1; Jemielita, 1991a; Appendix F1). Country rocks are strongly foliated, and sometimes folded, fine-grained, grey-green metavolcanics of the Alao-Paute subdivision. Foliation in the area trends N24°E and dips west 48°. Mine development comprises a decline 2 to 3 metres deep following two narrow quartz veins (15 cm wide) which cut the schist fabric at a large angle. The veins occupy brittle fractures trending N77°E dipping south 80° and comprise coarse, comb-textured quartz with vuggy terminations. Sulphides commonly occur near the walls of the vein and include pyrite, chalcopyrite, sphalerite and galena. Free gold was obtained from the oxidized veins. Wallrock alteration is absent or inconspicuous, but the veins are oxidized and show brown iron staining. This mineralization is considered to be polymetallic, hydrothermal vein-type of unknown genetic origin. No porphyry intrusions were observed in the vicinity.

The Tampanchi layered mafic-ultramafic pluton intrudes metamorphic lithologies of the Alao-Paute subdivision and is associated with anomalous Au values (Overseas Platinum Corp., 1988). Nearby alluvial gold claims support this to some extent but the alluvial gold is more likely associated with mesothermal quartz veins cutting the basement schists. A gold mine is noted on the (Cola de San Pablo 1:50000 scale) topographic map about 3 km SW of the village of Taday.

West of the town of Chigüinda (Map 4a), a 2 km-wide section of grey mica schists (Chigüinda subdivision) is hydrothermally-altered and pyritized (Jemielita, 1991c; Appendix F2). Values of up to 1082 ppb Au have been obtained at one locality, and base metals and molybdenum mineralization also occurs (Appendix D).

A "well defined" pegmatite belt north from Monte Olivo (Litherland et al., 1990), has, on closer examination, proven to be a belt of semi-pelitic mica schists with occasional bands of quartz-feldspar-muscovite ± tourmaline micropegmatite. Analysis of samples yielded very high silica and 0.069 g/T Au, but all other elements were disappointingly low (Appendix D).

About 2 km west of Monte Olivo (Map 7a), a prominent 10-metre-wide roadside exposure of white-yellow-red-brown coloured and hydrothermally altered greenschist (Monte Olivo subdivision) forms a visible feature trending ca. N20°E dipping 60°W, running down almost the entire height of the north slope of the Río Escudillas valley (Jemielita and Bolaños, 1992b; Appendix F7). The alteration is also visible climbing the south slopes of the valley. Alteration is sericitic and kaolinitic with colours due to iron oxides. Texture ranges from foliated to massive. No sulphides were noted but a channel sample was taken for analysis and assayed up to 450 ppb (0.45 g/T) Au (Appendix D). A previous rock-chip sample from this location yielded the following values: 471 ppm Cu, 79 ppm Pb, 144 ppm Zn and 17 ppm Ag (INEMIN-Misión Belga, 1988).

3.2 Silver

Historically, hard rock mining in the Cordillera Real from colonial times has been dominated by silver production. No production figures are available, but several locations e.g. Cubillín, Tungurahua, Condorazo (east of Riobamba), and Pilzhum (east of Azogues), are frequently mentioned as sites of silver mines (Navarro, 1986). Occurrences of silver mineralization are mentioned in geological map sheets No's 56, 72, and 73 (Ecuador, 1:100000 scale; Appendix B), and in Goossens (1972) and Ribadeniera (1960).

Silver occurs widely as an accessory metal in gold and/or polymetallic mineral deposits and prospects. High silver values in the Cordillera Real are usually associated with hydrothermal mineralization and alteration associated with andesite to rhyolite porphyry intrusions and volcanic and volcaniclastic rocks. The mineralization comprises intrusive breccia pipes, veins and disseminations and ranges from mesothermal to epithermal in character. High silver values are also associated with volcanogenic massive sulphide mineralization, and anomalous values are found in altered granodiorite intrusions and skarns.

3.2.1 Volcanogenic massive sulphide silver mineralization

Mineralized samples from the Guarumales (Río Paute) volcanogenic massive sulphide prospect (Map 4b; see Cu, Pb, Zn section below) also yield Ag values of up to 12.86 oz/T. These high Ag values are associated with gold and a range of base metals (Appendix D).

3.2.2 Volcanic-hosted epithermal silver mineralization

San Bartolomé: The San Bartolomé mine is located 1 to 1.5 km N and NW of the pueblo of the same name at an altitude of between 2800 metres and 3300 metres (Sigsig 1:50000 scale topographic sheet; Appendix A). Discovered during a UNDP study (Fozzard, 1985), the mine is presently owned and operated under a joint venture agreement between Banguet Corp. Canada Ltda. and Armenonic del Ecuador (Puig and Pazmiño, 1990). The mine area has been extensively and intensively explored by several organizations (INEMIN-Misión Belga, 1988). Mineralization occurs within fine- to coarse-grained Tertiary, andesitic porphyry lava flows thought to be underlain by meta-andesites of the Alao-Paute subdivision (Alao division). The mine has been explored by surface and underground drilling (6800 metres), exploration galleries (1600 metres) and surface trenches (200 metres), by United Nations projects between 1969 and 1978, and this work has been continued on several mine levels by the present owners.

Mineralization is hosted within fracture veins (5 to 10 cm wide) and veinlets. Bifurcations and horse-tails are common. Veins are of the steep and flat types and trend dominantly ENE. Two major NE to NNE-trending faults occur in the mine area. Mineralization is complex and includes sphalerite, pyrite, marcasite, galena, chalcopyrite, sulphosalts, arsenopyrite, native arsenic, tetrahedrite, pyrrhotite, boulangerite, polybasite, pearceite, sternbergite, pyrargyrite, freieslebenite and native gold. Gangue minerals are quartz, calcite, opal and adularia. Hydrothermal alteration includes strong argillization with quartz, sericite, chlorite, calcite, pyrite and tourmaline. Some alteration may be related to deep weathering.

Between 1969 and 1972 the United Nations projects reported reserves of 25 Mst (million short tons) at >2 oz/st silver and 1.1 Mst at 10 oz/st silver. Between 1976 and 1978, 94200 st of reserves were reported assaying 22.93 oz/st silver, 1.99% zinc; 0.68% lead and trace gold and cadmium (UNDP, 1972d, INEMIN-Misión Belga, 1988; Fozzard, 1985). The present owners report reserves of 100000 t at 20 oz/t silver, and a 100 t.p.d. mill is presently in operation.

Mineralization is of the complex polymetallic epithermal vein-type, hosted by young volcanic rocks. Economic potential is good and exploration is presently being extended towards the eastern (Shunaste) area.

Pilzhum: The Pilzhum area has long been known as a silver producer (Wolf, 1892). The Pilzhum mine area is located about 16 km from Azogues near the Taday road at an altitude of 3400 to 3765 metres (Map 2i; Jemielita, 1991a, b; Appendices F1 and F2). The mine and surrounding area has been examined by several individuals and organizations (INEMIN-Misión Belga, 1988). The country rock is a quartz-andesite or dacite porphyry stock of upper Tertiary or Quaternary age. Intrusive breccia is also present. Mine development comprises more than 600 metres of galleries and the remains of a mineral processing plant are visible. Ore mineralization includes pyrite, chalcopyrite, galena, sphalerite, enargite, tetrahedrite, proustite, bornite, chalcocite and covellite. Reported ore grades are silver 1500 g/t; gold 3.2 g/t, and copper, 2%. Gangue minerals are quartz and baryte. Hydrothermal alteration is mostly argillic, and is particularly strong adjacent to veins. Silicification and sporadic propylitic alteration also occurs.

Regional structural control of the Pilzhum deposit has been related to the southward extension of the San Antonio fault (Litherland et al., 1990). Locally, mineralization occurs within 19 to 23 known veins occupying a 3 km by 2 km zone. Dominant vein orientations are N20°E (dip subvertical), N80°E (dip subvertical or steep N), and N45° to 70°E (dip subvertical or steep S). The principal veins are 170 metres to 600 metres in length (INEMIN-Misión Belga, 1988). Mineralization is complex, polymetallic, epithermal vein-type, hosted by a porphyry intrusion. The mineralized system is large and economic potential is considered good for the discovery of further veins as well as breccia-hosted and, possibly, porphyry-style mineralization. The area has recently been drilled and trenched by a North American mining company.

Chinapintza: It is located in the southeast of Ecuador (Figure 6), has up to 250 g/t Ag reported (Clarke, 1989) from precious metals-bearing polymetallic, epithermal quartz veins related to high level dacite-rhyolite porphyry intrusions and volcanics. The mines in the area are worked for gold by artisanal miners and cooperatives, but the significant silver content of the gold produced reduces the price paid to miners for their product. The nearby Viche area also carries silver values associated with gold and base metals in diatremes, intrusive breccias and mineralized dacite-rhyolite volcanic rocks (Gemuts et al., 1992; see Gold-primary mineralization section).

Other areas: Other epithermal prospects carrying silver values include Los Planes (Ag 62 g/t), and Piuntza (Ag 38 g/t; Clarke, 1989; see Gold-Primary Mineralization section), in the Zamora batholith (Figure 6). Anomalous Ag values are also associated with altered and mineralized dacite-rhyolite porphyry intrusions and associated intrusive breccias e.g. Lomo del Loro < 11 ppm Ag, and Cerro Puglla 0.4 ppm Ag (Map 2f; Jemielita, 1991b; Appendix F2), Río Collay 13.1 ppm Ag (Map 4a; Jemielita and Bolaños, 1991b; Appendix F5), Gima-Cerro Colorado 6.8 ppm Ag (Map 3a; Jemielita, 1991c; Appendix F3), and altered and mineralized, andesite to rhyolite porphyry, volcanic and volcaniclastic rocks e.g. Cuchil 1.7 ppm Ag, and Principal 0.9 ppm Ag (Map 4a; Jemielita and Bolaños, 1991a; Appendix F4), Osogochi 1.8 ppm Ag, and Atillo 0.3 ppm Ag (Map 5b; Jemielita and Bolaños, 1991b; Appendix F5).

3.2.3 Porphyry-related silver mineralization

Fierro Urcu: It is a (porphyry-related) copper-molybdenum and precious metals (vein) prospect, located 14 km SW of Saraguro on the western flank of the Cordillera Real (see Cu, Zn, Pb section; Loja geological sheet 56; Appendix B). Abandoned adits in the area follow polymetallic veins exploited in colonial times for gold and silver. Silver assay values of up to 1464 g/T (most values below 10 g/T) have been obtained for vein samples (INEMIN-Misión Belga, 1988).

About 22 km south of Fierro Urcu at Uritohuaser, a fault-hosted, lead-zinc prospect, close to the contact between a granodiorite intrusion and andesitic volcanic rocks, yielded assay values of up to 33 g/T Ag (INEMIN-Misión Belga, 1988; Loja geological sheet 56; Appendix B).

Sigsig-Mina Peggy: Mina Peggy (Map 3a) carries significant silver values. Mineralization and geology of the Mina Peggy and surrounding area is detailed below (see Cu, Pb, Zn section; Jemielita, 1991a, b; Appendix F1 and F2). Mineralized samples often exceed 50g/t Ag (Appendix D), and values of up to 170 g/t (ppm) Ag have been reported. Mineralization comprises complex polymetallic veins, stockworks and intrusive breccias, probably related to young porphyry rhyolite intrusions.

Ayllón-Santa Bárbara: East of Mina Peggy, near the junction of the Río Santa Bárbara and the Río Ayllón (Map 4a), samples of polymetallic sulphide-bearing vein quartz ore from an abandoned mine yield >50 ppm Ag, as well as often spectacular gold and other metal values (Appendix D; see Gold-Primary Mineralization section). This vein, and others in the area, may be related to the Mina Peggy mineralization and this possible relationship is supported by the high arsenic values found in both systems (see Arsenic section).

Río Isimanchi: Anomalous Ag values (16.6 ppm) are also found in vein and/or disseminated sulphide mineralization associated with porphyry intrusions cutting the Neogene Portachuela granodiorite batholith around the upper reaches of the Río Isimanchi (Map 2a).

3.2.4 Miscellaneous silver mineralization

Silver values are associated with gold in skarn deposits of the Nambija area (Ag 17 g/t; Clarke, 1989).

Anomalous Ag values are also found in sulphide-mineralised and altered granodiorite intrusions and their (hydro) thermal aureoles e.g. Ishpingo 28.9 ppm Ag (Map 4a), Amaluza 5.5 ppm Ag (Map 4b; Jemielita and Bolaños, 1991a; Appendix F4), and Abanico-Upano 0.3 ppm Ag (Map 5a); in shear zones in schists at Laguna Negra-Atillo 0.9 ppm Ag (Map 5b; Jemielita and Bolaños, 1991b; Appendix F5), and Chigüinda 1 ppm Ag (Map 3a; Jemielita, 1991c; Appendix F3).

Litherland et al. (1990) report Ag values from the northern skarnfields e.g. at El Placer (5.8 ppm Ag), in the Río Chalpi (19 ppm Ag stream sediment anomaly), the Río Azuela NE of the volcano Cayambe (7 ppm Ag stream sediment anomaly), a siliceous, garnet-bearing hornfels from the Río Cofanes area (2 ppm Ag), also a nearby stream sediment heavy mineral XRF Ag peak (see Appendix E) in the Río Cofanes, upstream of La Sofia. 2.8 ppm Ag is also reported from a (491 ppb Au) Zn-vein rock in graphitic phyllites from the Río Papallacta.

High Ag values (up to 30%) are also reported from analyses of alluvial gold from rivers draining the Cordillera Real (Beddoe-Stephens, 1987, 1989; see Summary: Gold - Alluvial Deposits section).

3.3 Structural controls on primary gold-silver mineralization

The Las Aradas-Baños fault system generally corresponds with the contact between Tertiary volcanic and volcaniclastic rocks of the inter-Andean graben and metamorphic-plutonic lithologies of the Cordillera Real basement in Ecuador (Figure 2). In the south of the country, between Nabón (Río Shincata) and Sevilla de Oro (Río Collay), numerous alluvial gold-bearing rivers correspond geographically with the Baños fault, leading Aspden (in Litherland et al., 1990) to propose the existence of a (Collay-Shincata) "gold belt". Further studies along the Las Aradas-Baños fault system (Jemielita, 1991b, 1991c, Jemielita and Bolaños, 1991a; Appendices F2, F3 and F4), indicate that this structure appears to control several types of precious and base metals mineralization:

3.3.1 Mesothermal quartz (± gold) veins

Few occurrences of primary mesothermal vein quartz-gold mineralization have been recorded in the Cordillera Real. A notable exception occurs at the village of Cera which straddles the Las Aradas fault, northwest of Loja (Figure 7).

The widespread occurrence of massive, mesothermal vein quartz (sometimes associated with sulphides, ankerite and other carbonate minerals, tourmaline, chlorite, etc.) as boulders in auriferous alluvial deposits, and in basement-hosted veins, located along the Baños fault supports a genetic connection between alluvial gold and basement (shear zone) hosted, mesothermal quartz veins. This is further supported by often angular/poorly abraded alluvial gold grain morphologies which indicate local derivation (e.g. Ríos Shincata-Betas; Matanga; see relevant sections in Gold-alluvial deposits).

3.3.2 Volcanic-hosted epithermal and porphyry-related Au-Ag mineralization

Numerous prospects and anomalies of gold, silver and other metals are associated with volcanic-hosted epithermal (E) and porphyry-related (P) mineralization at locations along the Las Aradas-Baños fault e.g. Los Juanes (P, E), Uritohuaser (P), Fierro Urcu (P), Lomo del Loro (E), Cerro Puglla (E), Shincata (E), Gima-Cerro Minas (E), Mina Peggy (P), Cuchil (E), Loma Quipal (E), San Bartolomé (E), Principal (E), Río Collay (E), (Figure 7; see Gold- and Silver-Volcanic-Hosted Epithermal and Porphyry-Related mineralization sections for details). This geographical correlation strongly suggests that the Las Aradas-Baños fault exercised a fundamental control on the emplacement of mineralizing intrusions responsible for epithermal and porphyry-related mineralization.

Most of the mineralization described above occurs in the Saraguro-Sigsig section of the fault system which comprises a tensional jog on the dextral Baños fault (Figure 7).

Mine camps within the Nambija roof pendant (Figure 6) are, apparently, controlled by two, parallel, north-south trending faults spaced about 300 metres apart but, within individual mine camps e.g. Nambija and Campanilla, mineralization is controlled by northeast-trending brittle faults (pers. comm. A. Rogers, 1992). This fault geometry is consistent with dextral shear, similar to the dominant shear orientations observed in the Cordillera Real (pers. comm. J. Aspden, 1992).

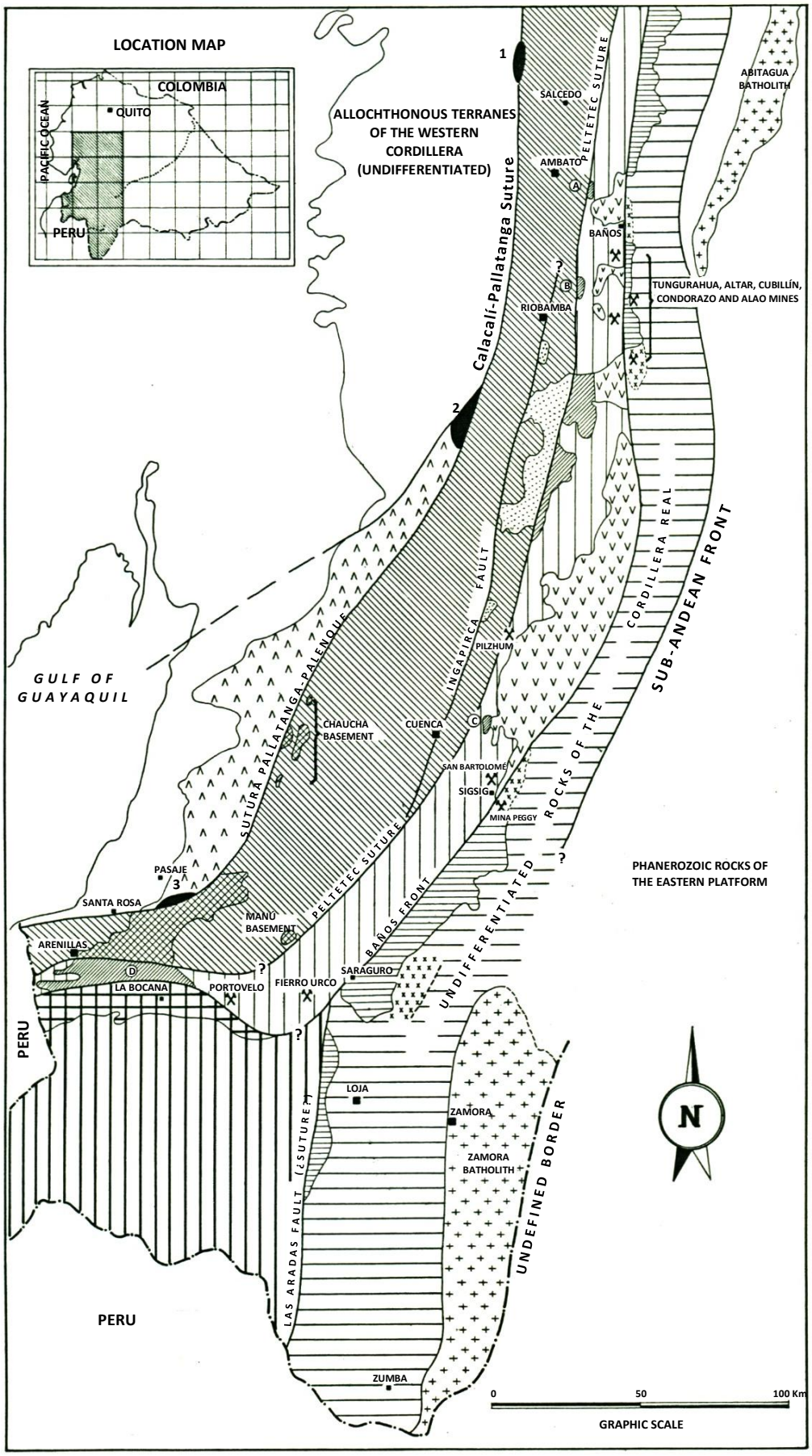

Figure 7. Locations of gold, silver and polymetallic mineralization in relation to the Las Aradas-Baños dextral transcurrent fault system (Modified after Aspden et al., 1988).

LEGEND

Predominantly undifferentiated metamorphic rocks of the Cordillera Real

Proposed westward extension of undifferentiated metamorphic rocks covered by younger rocks

WESTERN BELT OF THE CORDILLERA REAL (COLLISIONAL SEQUENCE)

Alao-Paute greenstone and metasedimentary division

Peltetec subduction complex including:

- Ⓐ Río Blanco de Patate gabbro
- Ⓑ Penipe ophiolitic rocks
- Ⓒ Oceanic sediments, turbidites, and olistostromes of the Río Paute-Jadán
- Ⓓ Raspas Complex: ultramafic rocks, blue and green schists

Undifferentiated divisions of the Western belt to the west of the Peltetec suture

The Alao-Paute division and the Peltetec subduction complex covered by younger rocks

CHAUCHA-ARENILLAS TERRANE

Generally high-grade metamorphic rocks including quartzite, amphibolite, schist, and gneiss with muscovite/biotite ± sillimanite

Proposed limits within the Peltetec (east) and Pallatanga-Palenque/Calacalí-Pallatanga (west) sutures covered by younger deposits

NONO-SHOBOL TERRANE (DEFINED BY MEGARD AND LEBRAT, 1986)

Principally basalt and andesite with low-grade metamorphic marine sediments

LA BOCANA TERRANE

High-grade metamorphic rocks including amphibolite, quartzite, migmatitic pelitic gneiss with garnet and para-autochthonous granite

Proposed southern extension toward Peru. To the east and north, the terrane is limited by the Las Aradas fault and the Baños front

OTHER UNITS

Ophiolitic complex of the Cordillera Occidental and its southern extension
1 = Pujilí-Saquisilí; 2 = Pallatanga; 3 = Palenque

Granitoid, schist, and gneiss frequently with blue quartz: tectonized rocks related to the Baños front

Calc-alkaline intrusives of probable Jurassic age

GEOLOGICAL SYMBOLS

Geological contact

Undetermined geological contact

Suture or major thrust/drag

Polymetallic mines related to the Western belt of the Cordillera Real and the Baños front

4. BASE METALS

4.1 Copper, Lead and Zinc

Numerous indications and occurrences of copper lead and zinc occur throughout the Cordillera Real as single metals or polymetallic mineralization. Some occurrences have been noted on (Ecuador 1:100000 scale) geological map sheets No's 39, 55, 56, 57, 58, 71, 72, 73NW (1:50000), 75, 85, 87, 88, 90, 96, 99, and 102 (Appendix B). Goossens (1969, 1972) mentions several occurrences of copper, lead and zinc in the Cordillera Real.

4.1.1 Volcanogenic massive sulphides Cu, Pb, Zn mineralization

Mina Pilas: Mina Pilas is located about 15 km NNE of Alao (Map 1) and comprises a bed of massive pyrite sandwiched between pyritized sericite schist and pyritized chlorite schist. The pyrite is auriferous (see Gold-Primary Mineralization section) and, although no base metal values are recorded in assay, the mineralization is considered to be a volcanogenic massive sulphide (VMS). VMS deposits can host significant copper, lead and zinc (e.g. see Guarumales prospect below; Hutchinson, 1980; Franklin et al., 1981), therefore, the Mina Pilas mineralization could indicate potential for base metals VMS mineralization elsewhere in the Alao-Paute and El Pan subdivision lithologies.

Guarumales: Within the black, grey and green mica schists of Upano subdivision lithologies (Salado division), on the east bank of the Río Paute, immediately downstream of the Guarumales bridge, about 60 metres of strongly mineralized schists and massive polymetallic sulphides are exposed as strongly brown iron oxide-stained rock in a roadcut (Map 4b; Jemielita and Bolaños, 1991a; Appendix F4). The mineralized rock is dominated by white and green mica schists with more or less fine- to medium-grained, disseminated pyrite. Massive sulphide beds occur within the schists. The sulphide beds range from a one-metre-thick bed of massive pyrite to narrower (ca. 10 cm thick) beds of finer-grained, granular, bedded and folded, polymetallic sulphides i.e. pyrite, chalcopyrite, galena, and other sulphides. Green malachite staining was observed, and a quartz-mica rich pod, with coarse chalcopyrite, sphalerite and other sulphides, was noted.

Assay values for samples from this location range up to 1.32% Cu, 7.97% Pb and 12.62% Zn, together with high or anomalous Au, Ag, As, Sb, Bi, Cd, Ba, Mo, W and Sn (Appendix D; see relevant sections for values). This is related to a polymetallic volcanogenic massive sulphide mineralization (Hutchinson, 1980; Franklin et al., 1981).

4.1.2 Volcanic-hosted epithermal Cu, Pb, Zn mineralization

Cerro Minas-Malacatus: Wolf (1892), reports the occurrence of galena, silver, zinc and fluorspar at Cerro de Santa Cruz (Cerro Minas), Malacatus. At Cerro Minas, near Malacatus (Map 2d), silver and gold values are associated with zinc and copper sulphides in an epithermal intrusive breccia associated with fluorite-bearing trachyte dykes (Jemielita, 1991b; Appendix F2).

Principal: A sample of mineralized volcanic (dacite) rock from the Principal area yielded 424 ppm Cu (Map 4a).

Pilzhum: The Pilzhum silver mine, northeast of Azogues, carries values of copper, lead and zinc (see Silver section).

Osogochi-Atillo: Young Tertiary dacite porphyry volcanics in the Cerro Soroche (Osogochi)-Atillo area (Map 5b; Jemielita and Bolaños, 1991b; Appendix F5) overlie basement lithologies of the Maguazo and Alao-Paute subdivisions (Alao division), and assay up to 2730 ppm Cu in places (Appendix D). Sulphide (pyrite) mineralization and hydrothermal alteration are widespread, but high Cu values are sporadic.

Chinapintza: In the Chinapintza mining area of southeast Ecuador (Figure 6) a suite of polymetallic (Cu-Pb-Zn-bearing), epithermal quartz veins (< 0.5 m wide) are hosted by coarse-grained granodiorite, tuffs and feldspar porphyries. Values of up to 0.04% Cu, 0.11% Pb and 5.27% Zn, associated with rich Au and Ag, have been obtained from grab samples, and sphalerite, argentiferous galena, pyrite, pyrrhotite and chalcopyrite have been identified petrographically (Clarke, 1989). The nearby Viche (or Biche) prospect comprises sulphide-mineralized diatremes and intrusive breccia pipes cutting sulphide-rich (pyrite and sphalerite), silicified and quartz-veined, dacite-rhyolite tuffs and lava flows. Mineralized samples contain anomalous copper, lead, zinc, silver and gold (Gemuts et al., 1992).

4.1.3 Porphyry-related Cu, Pb, Zn mineralization

Río Isimanchi: Values of Cu 3626 ppm, Pb 1318 ppm and Zn 10457 ppm (Appendix D) were recorded from a pyrite-cemented, feldspar-phyric, breccia dyke in the upper Río Isimanchi area (Map 2a; Jemielita 1991b; Appendix F2). The dyke cuts granodiorite of the Portachuela batholith which intrudes Loja division lithologies. Values of up to 2873 ppm Cu, 1086 ppm Pb and 915 ppm Zn have been recorded previously (Litherland et al., 1990) for samples from a sulphide-bearing shear zone associated with young porphyries which cut the Neogene Portachuela batholith.

Los Juanes: Wolf (1892), reports porphyry copper-style mineralization at San Miguel near Los Juanes to the south of Catamayo in the vicinity of the Las Aradas fault (Figure 7).

Fierro Urcu: It is a (porphyry-related) copper-molybdenum and precious metals (vein) prospect, located 14 km SW of Saraguro on the western flank of the Cordillera Real (Loja geological sheet 56; Appendix B). Abandoned adits in the area follow polymetallic veins, exploited in colonial times for gold and silver. Country rocks are Tertiary (Oligocene?) andesitic to rhyolitic volcanic and volcaniclastic lithologies intruded by dykes and plugs of granodiorite, and possibly underlain by lithologies of the Alao-Paute subdivision. The veins comprise milky quartz with tourmaline, pyrite, chalcopyrite, molybdenite, and traces of enargite, stibnite and other sulphides, and have yielded assay values of up to 3 % Cu, with traces of lead and zinc. Values of up to Cu (305 ppm), Zn (1570 ppm), and Pb (175 ppm), occur within two geochemically anomalous zones in the area, and an estimate of 53.5 million T of mineralized rock containing 0.2 % Cu has been made based on drilling (max. value Cu 0.315 %), probably in porphyry-style disseminated mineralization (INEMIN- Misión Belga, 1988).

Uritohuaser: About 22 km south of Fierro Urcu at Uritohuaser (Figure 7), a fault-hosted, lead-zinc prospect, close to the contact between a granodiorite intrusion and andesitic volcanic rocks, yielded assay values of up to 25 % combined lead and zinc (33 g/T Ag). Mineralization occurs as quartz veins associated with disseminated galena, sphalerite, pyrite and chalcopyrite (INEMIN-Misión Belga, 1988; Loja geological sheet 56; Appendix B).

Sigsig-Mina Peggy: Mina Peggy is located about 5 km SSE of the pueblo of Sigsig at an altitude of 2400 to 2800 metres (Maps 2h, 4a). The area straddles the Baños fault at the margin of the. Tres Lagunas granite batholith. The area has been described by several organizations and individuals (INEMIN-Misión Belga, 1988; Clarke, 1989; Litherland et al., 1990; Jemielita, 1991a, b; Appendices F1 and F2). Alluvial gold mining occurred historically in the vicinity of the Mina Peggy and is presently in operation in the nearby Río Santa Bárbara (see Gold - Alluvial Deposits section).

Country rocks comprise strongly deformed/mylonitized megacrystic biotite granite, quartz-sericite schist and mylonite of the Tres Lagunas subdivision (Loja division; Litherland et al., 1990). The dominant structure in the country rocks is a foliation trending N50° to 70°E. Deformation is attributed to shearing associated with the Baños fault.

A suite of young, undeformed, quartz-feldspar porphyry (rhyolite?) dykes and stocks intrudes the older lithologies, and crosscuts their pervasive schistose fabric. Mineralization comprises a porphyry (rhyolite)-related, mesothermal, polymetallic pebble dyke, together with an intrusive breccia pipe (300 to 400 metres long/diameter), as well as breccia dykes and veins. The Peggy vein, or pebble dyke, is about 10 metres thick and trends N45°W dipping SW at 80°. A 35-metre-wide exposure of the intrusive breccia pipe was observed in a roadcut 1.5 km to the north of the Peggy mine. The breccia is dominated by country rock (schist) fragments and is stained green in places with malachite. Mine development includes adits in the Peggy vein (pebble dyke), as well as several prospect adits and pits in the area. The most extensive workings occur within the large breccia pipe. The remains of an ore processing plant can be found near the mine.

Mineralization is complex with the following ore minerals reported: chalcopyrite, pyrrhotite, arsenopyrite, pyrite, marcasite, stannite, cassiterite, sphalerite, native bismuth, bismuthinite, wolframite and galena. Assay values reported for Mina Peggy ore are: 7.36% copper, 170 ppm silver, and 0.6 ppm gold. Gangue minerals include quartz, tourmaline and carbonates. Hydrothermal alteration is dominated by medium- to strong- argillization with some silicification and tourmalinization. The breccia-hosted mineralization has also been described (Clarke, 1989), and contains pyrite, arsenopyrite, sphalerite, galena marcasite, chalcopyrite, pyrrhotite, stannite, tetrahedrite and quartz.

Assay values for mineralized samples from the Mina Peggy and vicinity range up to Au 2660 ppm, Ag >50 ppm, As >2000 ppm, Sb 244 ppm, Bi >2000 ppm, Te 40 ppm, Cu >20000 ppm, Pb >10000 ppm, Zn >20000 ppm, Cd 1269 ppm, Ba 437 ppm, Mo 118 ppm, W 1242 ppm, and Sn 1242 ppm (Appendix D).

Mineralization at the Mina Peggy is complex, polymetallic, vein/stockwork and mineralized breccia, probably related to the young porphyry intrusions which outcrop in the area. Mineral potential is considered to be good, particularly with respect to concealed vein-stockwork, breccia-hosted and porphyry-style mineralization.

Ayllón-Santa Bárbara: East of Mina Peggy, near the confluence of the Río Ayllón and Río Santa Bárbara (Map 4a), polymetallic quartz veins, possibly related to the Mina Peggy mineralization, contain up to 2113 ppm Cu, 17200 ppm Pb and 30700 ppm Zn. These values are associated with sometimes spectacular Au values (up to 635 ppm Clarke, 1989), as well as Ag 246 ppm, As 22030 ppm, Sb 4900 ppm, Bi 29 ppm, and Cd 120 ppm Appendix D. These veins may be a peripheral manifestation of the mineralization at Mina Peggy.

Hito: The Hito porphyry copper prospect is located 5 km south of Chinapintza (Figure 6) and comprises coarse-grained, porphyritic granite, quartz diorite and granodiorite, intruded by quartz-feldspar and hornblende-pyroxene porphyries. Alteration comprises an outer propylitic halo with an inner sericite-pyrite core and samples containing chalcopyrite and quartz contain up to 1.8 % copper. Most other stockwork zones assay 0.1 to 0.5 % Cu, and there is no supergene enrichment (Gemuts, 1992).

4.1.4 Skarn Cu, Pb, Zn mineralization

Nambija: In the Nambija district (Figure 6) at the Campanillas mine coarse blocks of chalcopyrite and pyrite characterise the “copper zone” which was recently discovered during exploration (Andrew Rogers, mine geologist. pers. comm., 1991). Malachite also occurs in oxidized and gossanous exposures but these are not widespread.

Northern skarnfields: Cu-Pb-Zn mineralization is reportedly widespread in the northern skarnfields in the Cordillera Real (Litherland et al., 1990). At El Placer, values of up to 1347 ppm Cu were obtained from a tourmalinite, 278 ppm Pb and 4279 ppm Zn were also recorded. Up to 578 ppm Zn was recorded from the Urcucocha skarn field and up to 591 ppm at the Sara Urcu skarn field.

4.1.5 Granodiorite intrusion-related Cu, Pb, Zn mineralization

San Lucas: Pb and Zn geochemical anomalies are, reportedly, related to the Palaeogene San Lucas pluton north of Loja (Litherland et al., 1990).

Río Ishpingo: 2346 ppm Cu was recorded from a sample of hydrothermally altered and pyritized biotite granodiorite from the Río Ishpingo area (Map 4a).

Quebrada Quishpe-Alao: In the Río Alao valley and, to the north, chalcopyrite and malachite occur in auriferous veins cutting a Tertiary biotite granodiorite pluton in the quebrada Quishpe area (Map 1; Jemielita, 1991a; Appendix F1). These latter occurrences are considered to be fracture-controlled, hydrothermal vein mineralization.

4.1.6 Miscellaneous Cu, Pb, Zn mineralization

Chigüinda: Rocks exposed in outcrop and road-cuts on the Sigsig-Chigüinda road, between the Río Blanco bridge and the pueblo of Chigüinda (Map 3a; Jemielita, 1991c; Appendix F3), comprise variably altered and mineralized mica schists characterised by strong yellow-brown colouration. The mineralized area is exposed for ca. 2 km along the road. Country rocks comprise strongly foliated/sheared, fine-grained, grey to black and green mica schists (Chigüinda subdivision). Foliation trends north-northeast (N36°E, N34°E) and dips variably, steep to vertical. Hydrothermal alteration is ubiquitous and mostly visible as yellow-brown, iron oxide staining. Sericite schists and granular (sugary-textured) quartz-rich schists are common.

Mineralization comprises fracture coatings and quartz veins with sulphides. Sulphide minerals include pyrite, chalcopyrite, galena, sphalerite and molybdenite. Vein quartz textures are generally vuggy, indicating epithermal-mesothermal conditions, but milky-white, massive vein quartz also occurs. Pyrite is also commonly disseminated throughout the altered schists.

Assay values for mineralized samples from the area range up to Cu 224 ppm, Pb 2030 ppm, Zn 216 ppm, and these values are associated with anomalous Au 1082 ppm, As 20 ppm, Sb 41 ppm, Bi 49 ppm, Ba 152 ppm, Mo 4396 ppm (Appendix D).

The strong foliation within the altered and unaltered mica schists suggests that these rocks have been deformed in a shear zone, but the mineralization has characteristics typical of epithermal-mesothermal porphyry-related systems. Viteri and Aspden (1989), noted the occurrence of young porphyry intrusions in the area and the mineralization may be related to these. No porphyry intrusions were, however, noted along the road-cut exposure.

7189 ppm Cu was recorded from a mineralized float block of Tertiary felsic volcanic rock at Río Tintas near Principal (Litherland et al., 1990).

Amaluza (Río Paute): Stream sediment anomalies of up to 2300 ppm Zn occur as a cluster along the Río Paute near the Palaeogene Amaluza granodiorite pluton, close to the Baños fault (Litherland et al., 1990; Appendix E). These anomalies may correspond to Zn-Pb-Mo anomalies noted on the Cañar geological sheet No. 72 (Appendix B).

Cerro Hermoso-Llanganates: Cerro Hermoso contains only a few small Cu-Zn veins in the carbonate sequence (Litherland et al., 1990).

Alao Division lithologies: Within the Peltetec and Maguazo subdivision (Alao division) lithologies, small copper occurrences are reported in serpentinites, and as Cu-Zn veins in the adjacent Maguazo turbidites (Litherland et al., 1990), as well as a Zn anomaly in the Patate area. Strong malachite mineralization, and associated copper sulphides, occur in sheared turbiditic sediments of the Maguazo subdivision in, the quebrada Huarguallá (Map 1). This mineralization may be syngenetic in nature. Within the Alao-Paute and El Pan subdivisions (Alao division), greenstones and greenschists host polymetallic veins near the village of Alao (Mina Cruzacta, Mina Curiayana; Map 1; Jemielita, 1991a; Appendix F1). These occurrences are exposed in small exploration adits of unknown antiquity but the mineralization is not significant and no extensive production is indicated.

Agua Santa: A small exploration adit (Mina Agua Santa) exposes a vein containing strong pyrite-chalcopyrite-bornite mineralization in the Río Alao valley (Map 1; Jemielita, 1991a; Appendix F1).

Condorazo: The legendary Condorazo mine (Navarro, 1986) is located north of the Río Alao-Río Palora watershed (Map 1; Jemielita, 1991a; Appendix F 1).

The vein is somewhat discontinuous but can be traced along strike for more than 200 metres. Vein trend is approximately N170°E dipping 74°W. The walls of the vein are strongly sheared granite with a vein-parallel fabric but, on a larger scale, the vein is discordant with respect to the regional fabric.

Mineralization is dominated by a thick (up to 2 metres wide) vein of milky-white quartz which outcrops as an upstanding ridge. Large, irregular masses of oxidized pyrrhotite occur in the vein sporadically, and inclusions of granular granite country rock are present. Yellow-weathering, coarse, carbonate vein material sometimes occurs. Mineralized waste samples in the vicinity of the summit adit are variable in composition and include brown, altered granite with disseminated pyrite; white, granular granite with disseminated galena; and pyrite and massive pyrite-pyrrhotite. Wallrock waste from the north adit comprises altered schist and granite, the latter bearing orange-coloured, weathered dolomite/ankerite micro-veinlets.

Mineralization is mesothermal, polymetallic vein-type, related to brittle/ductile structures.

Litherland et al. (1990) report small, concordant Pb-Zn-Cu-bearing veins in sheared Tres Lagunas granite in the Río Alao-Río Palora watershed to the south of Condorazo.

Río Quijos: In the Río Quijos, above the Río Papallacta confluence, there are blocks of quartz-calcite vein material in graphite schists with values up to 7593 ppm Zn (Litherland et al., 1990).

Salado Division: Traces of Cu, and to a lesser extent, Pb and Zn, are common in Salado division lithologies, especially in mylonitic rocks (e.g. Río Cofanes; Litherland et al., 1990), and strongly epidotised and mylonitized greenstones (e.g. Río Santa María-Oyacachi, Map 6a; Jemielita and Bolaños, 1992a; Appendix F6). In the meta-sediments of the Upano subdivision along the Río Upano, weak Cu-mineralisation is found in four greywacke localities (Litherland et al., 1990).

Río Chingual-Río Cofanes: In the extreme north of the country, 4% Zn was recorded from a mineralised sample in Quebrada La Industria, a tributary of the Río Chingual (Map 7d). The rock is a fine-grained banded “cherty” garnet hornfels of volcano-sedimentary affinity. According to Litherland et al. (1990), this horizon can be traced west of Rosa Florida but there are also mineralised float blocks further west in the tributaries of the Río Cofanes. Although grouped with the Zamora division, this unit is transitional with the Salado division.

Other localities: Litherland et al. (1990) report traces of Pb and Zn near Pimampiro in the north of Ecuador, as well as indications of Zn at Oyacachi (Arguello and Lamina, 1989), and Zn-Cu-bearing veins near the Agoyán tunnel (east of Baños). The latter area is characterised by strong, brown, iron oxide staining of the country rock schists and, a few hundred metres downstream on the south bank of the Río Pastaza, cliffs are marked by a sub-vertical zone of yellow-white alteration. This location is very inaccessible and was not sampled.

Zamora Division: According to Litherland et al. (1990), Cu, Pb and Zn occurrences are associated with igneous, volcanic and sedimentary subdivision lithologies of the Zamora division.

Strong Cu-Pb-Zn (-Co) fluvial geochemical anomalies and a Zn mineral showing are probably related to the Zamora batholith and Misahuallí subdivision volcanic rocks in the Río Cuyes and Río Yacuambí areas.

Further south Cu-Pb-Zn indications are related to all three Zamora subdivisions and galena was noted in marbles close to volcanic rocks of the Isimanchi subdivision near Valladolid.

4.2 Cadmium

Assay values of up to 730 ppm cadmium have been obtained from polymetallic volcanogenic massive sulphide and associated mineralized schist horizons at Guarumales on the Río Paute (Map 4b; see Cu, Pb, Zn section).

Very high cadmium values of up to 2269 ppm have also been obtained from mineralized rock samples from the Mina Peggy near Sigsig (Appendix D; see Cu, Pb, Zn section). Similar high values have been reported previously (Litherland et al., 1990).

5. METALLOIDS AND MERCURY

5.1 Arsenic

Samples from the Guarumales (Río Paute) volcanogenic massive sulphide prospect have yielded As values exceeding 2000 ppm (Appendix D), together with high values of precious and base metals and barium (see Cu, Pb, Zn section).

Wolf (1892), reported the occurrence of arsenic as sulphosalts in the Pilzhum epithermal silver mine area.

A value of 1143 ppm As was obtained from a sample of coarse, clast-supported, pyritized dacite intrusive breccia associated with other intrusive breccias and an epizonal dacite porphyry plug at Lomo del Loro, near Saraguro (Map 2f; Appendix D).

Massive and crystalline arsenopyrite is common in mineralized samples from the Mina Peggy near Sigsig (Map 4a; Jemielita, 1991b; Appendix F2) and assay values frequently exceed 2000 ppm (appendix D; Clarke, 1989). Arsenic is associated with precious and base-metals and other rare metals and the mineralization is thought to be of the porphyry-(rhyolite) related, mesothermal breccia/vein type (see Cu, Pb, Zn section).

East of Mina Peggy, near the confluence of the Río Santa Bárbara and Río Ayllón, arsenopyrite occurs in massive vein quartz associated with chalcopyrite, sphalerite and other sulphides and sulphosalts (Map 4a; Clarke, 1989). Samples of this material from an abandoned mine assay more than 2000 ppm As and yield high values of gold, silver, base metals, and antimony (Appendix D). Boulders of similar mineralized vein material were observed in the Río Santa Bárbara, downstream near the Mina Peggy. This mineralization is considered to be mesothermal polymetallic vein-type and is probably porphyry-related.

Other anomalous arsenic values include 95 ppm As in a pyritized rhyolite intrusion at Cariamanga (Cariamanga 1:50000 scale topographic sheet); up to 70 ppm As in bedded rhyolite breccias at Cuchil (Satunsaray) near Sigsig (Map 4a); up to 67 ppm As in hydrothermally altered and pyritized dacite porphyry volcanics near Osogochi (Map 5b); up to 124 ppm As from a hydrothermally altered and pyritized granodiorite in the Río Ishpingo area (Map 4a); up to 43 ppm As in altered and pyritized, hornfelsed metasediments around the Amaluza granodiorite in the Río Paute (Map 4b) and, up to 423 ppm As in similarly hornfelsed and mineralized sediments and metasediments around the Sabanilla granodiorite in the Río Abanico-Río Upano area near Macas (Map 5a).

These latter anomalous As values are associated with hydrothermally altered and mineralized dacite-rhyolite porphyry intrusions and volcanics, and granular biotite-hornblende granodiorite intrusions and their hornfelsed aureoles. The granodiorites are thought to be part of a Tertiary comagmatic suite.

5.2 Antimony

Antimony mineralization mostly occurs with precious, base and other metals associated with porphyry-related, mesothermal, volcanic-hosted epithermal, and volcanogenic massive sulphide mineralization. The occurrences of high and anomalous assay values for antimony generally correlate with similar values for arsenic.

Samples from the Guarumales (Río Paute) volcanogenic massive sulphide prospect yielded up to 1228 ppm Sb (see Cu, Pb, Zn section).

Wolf (1892), and Goossens. (1972) reported the occurrence of antimony as sulphosalts in the Pilzhum epithermal silver mine area.

The antimony minerals boulangerite, polybasite and freieslebenite are reported from the San Bartolomé silver mine (UNDP, 1972a).

Sb values of up to 207 ppm were found in mineralized rocks from the Mina Peggy area, and 244 ppm Sb in samples from the nearby quebrada Reote (Maps 2h, 4a; see Cu, Pb, Zn section).

The highest Sb values encountered (>2000 ppm) are for samples of quartz-arsenopyrite (Au, Ag, Cu, Pb, Zn, As, Sb) veins from an abandoned mine near the confluence of the Río Santa Bárbara and Río Ayllón (Map 4a). Values of up to 0.49 % Sb have been recorded in samples from this location and boulangerite ($Pb_5Sb_4S_{11}$) and bournonite ($PbCuSbS_3$) recognized in samples (Clarke, 1989).

Other Sb anomalies include: Up to 28 ppm from samples from the Lomo del Loro dacite porphyry plug and intrusive breccia complex near Saraguro (Map 2f); from 9 to 14 ppm Sb in hydrothermally-altered and pyritized dacitic porphyry volcanics in the Osogochi-Atillo areas (Map 5b); and up to 17 ppm Sb in hydrothermally-altered and mineralized granodiorites and/or their hornfelsed metasedimentary host rocks at the Río Ishpingo (Map 4a), Amaluza (Río Paute; Map 4b), and Sabanilla (Río Abanico-Río Upano; Map 5a) plutons.

Litherland et al. (1990) describe up to 402 ppm Sb from a mineralized zone at Laguna Cox where felsite dykes cut lithologies of the Portachuela batholith. They also report two XRF “trace” Sb peaks (see Appendix E), from heavy mineral stream sediment samples from a mineralized region at the headwaters of the Río Cuyes.

5.3 Bismuth

Bismuth was noted in tetrahedrite from the Pilzhum epithermal silver mine near Azogues (Putzer and Schneider, 1958).

Bismuth values exceeding 2000 ppm were obtained for mineralized samples from the Mina Peggy (Appendix D; see Cu, Pb, Zn section). Litherland et al. (1990) previously reported similar high values up to 5800 ppm from the same location. Native bismuth and bismuthinite are reported from the Mina Peggy (de Coster, 1986).

Bismuth values are generally low or undetectable in other assayed samples from the Cordillera Real with the following exceptions:

Up to 56 ppm Bi in samples from the Guarumales volcanogenic massive sulphide prospect (Río Paute; Map 4 b; see Cu, Pb, Zn section); 49 ppm from a pyritized schist near Chigüinda, east of Cuenca (Map 3a); 29 ppm from a gold-rich, polymetallic vein sample from the Río Ayllón (Map 4a; see Gold-Primary Mineralization section); 26 ppm from a sample from the Río Isimanchi (Map 2a; 29 ppm previously reported from this area, Portachuela batholith occurrences of Litherland et al., 1990); 14 ppm from unspecified sample from the northern skarnfields (Litherland et al., 1990), and tentative identification of bismuth and bismuthinite in heavy mineral samples from the Río Mulatos (op. cit). Bismuth telluride had also been reported in auriferous alluvial heavy mineral pan concentrates in the quebrada Quishpe east of Riobamba (Alex. Hirtz, pers. comm., 1991; Map 1; Jemielita, 1991a; Appendix F1). This river drains a Tertiary granodiorite intrusion which hosts polymetallic vein mineralization (see Cu, Pb, Zn section).

With the exception, perhaps, of the Mina Peggy, none of these occurrences of bismuth can be regarded as of commercial interest.

5.4 Mercury

Ribadeneira (1960) reports mercury mineralization at Cerro Huaizhun near the town of Azogues (Azogue is a Spanish word meaning mercury), north of Cuenca. This location was, apparently, mined for mercury (Chacón, 1986), and probably comprises volcanic-hosted epithermal mineralization. This mineralization is also shown on the Azogues geological map sheet 73NW (Ecuador, 1:50000 scale; Appendix B), and is mentioned by Goossens (1972). The United Nations Development Programme also conducted studies in the area (UNDP, 1972a).

6. METALS OF THE MAFIC/ULTRAMAFIC INTRUSIVE ASSOCIATION

6.1 Platinum Group Metals (PGM)

Alluvial gold and platinum concessions were held between 1900 and 1920 in the Río Pindilig-Río Cochicorral area, east of Azogues (Navarro 1986, Vol 3. Appendix). These rivers drain eastwards across the Tampanchi layered mafic-ultramafic intrusion (Pozo, 1990) which was discovered in 1987 by the Cordillera Real project and interpreted as being an Alaskan-type intrusive pipe (Litherland et al., 1990; Irvine, 1974; Naldrett, 1981). The presence of mineralogical differentiation and cumulate textures within the intrusion, together with its composition, suggests a probable source for the alluvial platinum and, possibly, gold. Subsequent commercial surveying has confirmed this likelihood (Overseas Platinum Corp., 1988). Values of up to 1908 (or 1980?) ppb Pt and 2568 ppb Pd (stream sediment pan concentrates), 205 ppb Pt and 260 ppb Pd (soils), and 195 ppb Pt, 199 ppb Pd (rock) have been reported.

Other mafic-ultramafic intrusions are known within the Cordillera Real and ophiolitic occurrences have been documented (Litherland et al., 1990), but no other showings of alluvial or primary PGM mineralization have been recognized.

Platinum has also been reported in refined gold smelted from ore from porphyry-related, epithermal, polymetallic veins at Chinapintza in southeastern Ecuador (Trevor McLaughlin, pers. comm., 1992). This may reflect the trace amounts of platinum group metals that have been found in some epithermal gold and porphyry copper deposits in the U.S.A. and Canada respectively (Page et al., 1992a, b).

6.2 Chromium

Assay values for chromium in mineralized samples from the Cordillera Real are usually at low or background levels. Some occurrences of chromium have been reported:

Apparently unmineralized ultramafic rocks from the Peltetec (ophiolite) subdivision yield up to 1092 ppm Cr in assays. This appears to be a normal value for ophiolitic rocks (Litherland et al., 1990).

Chromite blocks have been reported in the hills near the Río Zula and to the south along the Peltetec ophiolite belt (A. Hirtz, pers. comm. in Litherland et al., 1990), and a small lead-zinc mineralized vein close to Peltetec gave 1600 ppm Cr.

A stream sediment Cr value of 651 ppm is reported from a quebrada draining serpentinites at Peltetec.

Cr anomalies are reported in the Patate-Pastaza area where they are likely related to tectonic slices of ophiolite.

To the east of the Baños fault, chromite has been identified petrographically in the Soledad serpentinite. Further east, an apparently unmineralized block from the Urcucocha serpentinite yielded 4079 ppm chromium. A serpentinite block from the Río Cofanes gave 2216 ppm Cr.

Chromite grains have been identified in heavy mineral stream sediment samples taken during the Cordillera Real project (Litherland et al., 1990).

The green-coloured chromian-mica, fuchsite, has been observed at various localities throughout the Cordillera Real. To the west of Monte Olivo (Map 7a) a fuchsitic serpentinite gave 1410 ppm Cr. A fuchsite-bearing, impure dolomite comprises a marker band in the Cuyuja nappe stratigraphy in the Río Cosanga.

Cr anomalies of up to 422 ppm are reported, apparently related to the San Lucas pluton south of Saraguro.

A "strong" Cr XRF peak (Appendix E) was detected in a heavy mineral sample from Río Panguri in the La Canela sector, close to vanadium geochemical anomalies.

"Strong" and "moderate" XRF Cr peaks (Appendix E) were detected in heavy mineral samples from the Tampanchi mafic-ultramafic complex. These rocks show good evidence of cumulate settling textures and may contain chromite horizons.

In the vicinity of the Tampanchi ultramafic intrusion (Pozo, 1990) the following values of Cr have been recorded (Overseas Platinum Corp., 1988): 9842 ppm Cr (max. stream sediments); 2187 ppm (rock); and 4863 ppm (soil).

6.3 Nickel

Nickel mineralization is mentioned in (Ecuador 1:100000 scale) geological sheet No. 87 (Appendix B). Nickel (along with chromium and PGM's) is usually associated with mafic-ultramafic intrusions. The relative paucity of rocks of this composition in the Cordillera Real is reflected in the scarcity of high Ni values.

A value of 2061 ppm Ni was obtained from the Zumba serpentinite, and values of 500 to 2000 ppm Ni for ultramafic rocks from the Cordillera Real (Litherland et al., 1990) correlate with similar values for ophiolitic rocks worldwide (Hutchison, 1983).

Samples taken in the vicinity of the Tampanchi ultramafic intrusion (Pozo, 1990) yielded the following maximum Ni values (Overseas Platinum Corp., 1988): 642 ppm (rock); 1095 ppm (soil).

A stream sediment anomaly of 801 ppm Ni (corresponding with 651 ppm Cr) was obtained from a stream draining serpentinites at Peltetec.

One sample of the Mulatos skarn contains 5% pyrrhotite (Litherland et al., 1990), but no Ni values are reported. Sauer (1965) reported 1.5% Ni in the Río Mulatos (Río Parcayacu?) ophiolite but this occurrence has not been confirmed.

All other assay values for a wide variety of mineralized rock samples from the Cordillera Real yield less than 198 ppm Ni (Appendix D).

The rapid rate of uplift and erosion of the Cordillera Real does not permit formation of deep tropical soils and, together with the general lack of ultramafic lithologies, means that the potential for nickeliferous laterites is considered to be non-existent.

6.4 Cobalt

Litherland et al. (1990) report a value of 236 ppm Co in a skarn block from the Río Quijos above its confluence with the Río Papallacta. They further report Co stream sediment anomalies (see Appendix E) in Tutupali, and in two tributaries of the Río Cuyes, west of Gualaquiza.

A maximum value of 174 ppm Co was obtained for a rock sample from the Tampanchi ultramafic intrusion (Overseas Platinum Corp., 1988; Pozo, 1990).

6.5 Vanadium

Litherland et al. (1990) report the following Vanadium analyses: 334 ppm and 289 ppm V corresponding with high molybdenum values from the Urcucocha skarnfield; 244 ppm from a garnet granite near Oyacachi; 242 ppm and 300 ppm V from rock samples in the quebrada Cambana; 296, 316 and 655 ppm V in stream sediments (see Appendix E) in the Río Vergel area (SE part), corresponding with similar Fe, Ti, Zn and Cu stream sediment values.

6.6 Titanium

An occurrence of titanium mineralization is mentioned in geological sheet 71 (Ecuador 1:100000 scale; Appendix B). Litherland et al. (1990) report large (up to 4 cm long), brownish-red rutile crystals in pegmatised gneisses east of Monte Olivo (Map 7a). The occurrence is classed as a mineralogical curiosity only.

Values of 0.40% Ti and 0.44% Ti apparently correspond with the highest Mo-V values in samples from the Urcucocha skarnfield. Stream sediment Ti anomalies of up to 1.04% Ti correspond with vanadium anomalies in the Río Vergel area.

7. FERROUS METALS

7.1 Iron

Iron-bearing minerals have been reported in the following (Ecuador 1:100000 scale) geological sheets (Appendix B):

Mineral	Sheet
Goethite	86
Magnetite	71
Pyrite	57, 72, 75, 85, 90, 96, 99, 100, 101, and 102.
Glauconite	102
Limonite	96

Magnetite float blocks have been reported in rivers draining the Zamora batholith (Litherland et al., 1990), and two quebradas in the vicinity of the Nambija gold skarn mining area are known as quebrada Fierro and quebrada Hierro respectively (Zamora 1:50000 scale topographic sheet; Appendix A). Fierro and hierro are Spanish words for iron and steel. Small float blocks of magnetite (<20 cm across) have been noted along the Río Yacuambí especially near the confluence with the quebrada Cambana. Pebbles and boulders of massive magnetite are common in alluvial mining waste in the auriferous quebrada Cambana, located to the north of Nambija. The source of the magnetite in the Zamora batholith is likely to be skarn mineralization which is common in the area.

Magnetite is also, reportedly, common in the northern skarnfields of the Cordillera Real but no large boulders have been observed (Litherland et al., 1990). These skarns have been classified as being of the calcic-magnetite-type, known elsewhere in the world to be associated with magnetite ore bodies. Veins of specular hematite are reported to occur west of Cerro Pan de Azúcar (Sr, Alex Hirtz, pers. comm., 1991). Iron mineral localities are shown in this vicinity in the metallogenic map of Paladines (1980).

Pyrite (FeS_2) occurs widely in almost all lithologies in the Cordillera Real. Pyrite is particularly concentrated in the volcanogenic massive sulphide deposits of Mina de Pilas and Guarumales (see Gold-Primary Mineralization and Cu, Pb, Zn sections). Elsewhere, pyrite usually occurs disseminated in altered volcanic rocks and, rarely, as an alluvial mineral (e.g. Principal-Río Shio, Map 4a; Cerro Tintillay-Osogochi, Map 5b).

None of the above types of iron mineralization are considered to have economic potential at present.

7.2 Manganese

Occurrences of manganese mineralization are mentioned in geological map sheets No's 55 and 96 (Ecuador 1:100000 scale; Appendix B). Litherland et al. (1990) report a personal communication of vein manganese in the Peltetec region but no other details are available.

Small Quaternary deposits of manganese wad are associated with carbonated water springs in the Río Pan valley near El Carmelo in the north of Ecuador on the Colombian border (Jemielita and Bolaños, 1992b; Appendix F7). These deposits occur within an area of Quaternary volcanic and volcaniclastic rocks but are of no economic significance at present.

Dusty, black, fracture coatings of manganese oxides were noted locally at the Campanillas gold mine in the Nambija district.

8. GRANOPHILE METALS

8.1 Molybdenum

Molybdenum mineralization is mentioned in geological sheets No's 39, 56, 72, 73, (Ecuador 1:100000 scale) and 73NW (1:50000 scale; Appendix B). Molybdenite has been identified at widely different locations throughout the Cordillera Real but is not abundant. Molybdenum mineralization usually occurs in the form of molybdenite (MoS_2) and, less commonly, the secondary mineral ferrimolybdite ($Fe_2(MoO_4)_3 \cdot 8H_2O$?).

Fierro Urcu is a (porphyry-related) copper-molybdenum and precious metals (vein) prospect, located 14 km SW of Saraguro on the western flank of the Cordillera Real (see Cu, Zn, Pb section; Loja geological sheet 56; Appendix B). Anomalous Mo values of up to 45 ppm have been reported from the area and molybdenite occurs in a quartz vein (veta Ancha) associated with other sulphides and sulphosalts (INEMIN-Misión Belga, 1988).

Traces of molybdenite are reported from Uritohuaser, 22 km south of Fierro Urcu associated with a fault-hosted, lead-zinc prospect (INEMIN-Misión Belga, 1988). A fluvial Mo (Cu) anomaly exists a few kilometres NW of this location (Loja geological sheet 56; Appendix B).

Litherland et al. (1990) report fine, disseminated molybdenite, with larger (up to 1 cm) pyrite crystals exposed for two to ten metres width in a massive, green, epidote skarn with a sub-horizontal fracture foliation. The mineralized rock occurs from the summit ridge of the Urcucocha skarnfield east to Laguna Urcucocha. The platey molybdenite grains are associated with hairline veinlets of carbonate (retrograde alteration of the skarn?), and analyses range from 0.3% to 0.5% Mo. A sample from the Sara Urcu skarnfield yielded 556 ppm Mo, and 113 ppm Mo was recorded from the El Placer skarnfield.

About 3 km east of the town of Monte Olivo a river (San Miguel; Map 7a) exposure of strong, brown-yellow, iron oxide staining is related to a deformed and discordant, massive, quartz vein containing abundant pyrite and, less commonly, grains of molybdenite with its characteristic powder-yellow alteration product ferrimolybdite. The vein is tens of centimetres thick and partly gossanous. A possible extension of the vein outcrops on the opposite (W) side of the river. A sample of the vein assayed 964 ppm Mo. River boulders in the Río San Miguel, immediately south of Monte Olivo, include quartz-feldspar pegmatite with molybdenite (and chalcopyrite), and a granular feldspar rock with coarse blebs of pyrite and molybdenite. Mo-Cu mineralization has been noted previously in a quartz float block from this location (INEMIN-Misión Belga, 1988).

Molybdenite flakes were noted in quartz veins cutting the mafic (gabbro pegmatite) contact zone of the Chingual batholith along the old road to La Bonita (Litherland et al., 1990).

Ribadeneira (1960) reports molybdenite in pegmatites near the hacienda Ilade, Río Anzu.

Molybdenite flakes (and yellow ferrimolybdite) occur in massive white vein quartz cutting strongly altered mica schists at one locality within a ca. 2 km wide, altered and mineralized zone near Chigüinda (Map 3a; Jemielita, 1991c; Appendix F3). An assay of 4396 ppm was obtained for one sample (Appendix D).

A similarly altered and mineralized zone in mica schists along the San Antonio road (SE of Yangana; Map 2c) contains vuggy quartz veins and, at one locality, molybdenite and ferrimolybdite coating fracture surfaces. An assay value of 63 ppm Mo was recorded (Appendix D). In the nearby Río Chiriguana (Yangana) a value of 107 ppm Mo was obtained from a sample of iron oxide-stained schist with coarse, vuggy, vein quartz and pyrite (Appendix D).

Other locations yielding Mo values include up to 76 ppm Mo from the Guarumales VMS prospect (Map 4b); up to 90 ppm Mo from the sulphide-mineralized and altered Ishpingo granodiorite (Map 4a); up to 118 ppm Mo for mineralized samples from the Mina Peggy area (Map 4a); up to 56 ppm Mo from altered and pyritized dacite porphyry volcanics in the Cerro Pucurcu Grande-Atillo areas (Map 5b); 38 ppm Mo from the Cerro Puglla mineralized breccia (Map 2f); and up to 30 ppm Mo from the Gima (Cerro Colorado) mineralized porphyry breccia (Map 3a). Assay values of up to 13 ppm Mo have been recorded from other areas (Appendix D).

A cluster of stream sediment geochemical Mo anomalies are noted on the Cañar geological sheet (No. 72; Appendix B), coincident with Zn-Pb anomalies east and west of the Río Paute, near the Amaluza granodiorite intrusion (Map 4b; Litherland et al., 1990).

Litherland et al. (1990) report heavy mineral XRF analyses (see Appendix E) showing a cluster of “weak” Mo peaks from samples from streams draining north into the Río Isimanchi near the Peruvian border. These probably relate to mineralization in high level felsitic phases within the Portachuela batholith. A value of 11 ppm Mo has been obtained for a float boulder of pyritized, silicified and epidotized serpentinite or skarn from this area (Appendix D).

Another Mo peak occurs in the Río Salado Chico draining an Azafrán phase granodiorite west of Macas (Map 5a; Litherland et al., 1990).

World class (Climax-type) molybdenum deposits are associated with anorogenic (A) type granites emplaced in rifted cratonic settings (White et al., 1991). No intrusions of this composition are known in Ecuador, and the tectonic setting suitable for their generation is lacking.

8.2 Tungsten (Wolfram)

Tungsten mineralization is mentioned in geological (Ecuador 1:100000 scale) sheets No’s 55, 58, and 75 (Appendix B).

Tungsten occurs in mineralized samples from the Mina Peggy, with assay values up to 5979 ppm W (Appendix D). Wolframite of 60 to 70% ferberite composition has been identified in these samples (Litherland et al., 1990).

Values of up to 444 ppm W were obtained from samples from the Guarumales volcanogenic massive sulphide prospect (see Cu, Pb, Zn section; Appendix D).

A value of 59 ppm was obtained for a mixed sample of iron oxide-stained, grey-green coloured schist boulders from the Río Agua Clara in the north of the country (Map 7c). A pegmatite cutting the Tres Lagunas granite near Loma del Inca yielded 32 ppm W and an impure siliceous marble from the El Placer skarnfield gave 23 ppm W (Litherland et al., 1990).

Other known tungsten occurrences (Litherland et al., 1990) are restricted to scheelite, recognized in heavy mineral pan concentrates of stream sediments from the following locations: Río Cofanes-La Bonita-Rosa Florida with a cluster of 20 to 100 grain scheelite samples; Río Oyacachi-Río Papallacta with six, 100-grain scheelite occurrences, possibly related to Ag-Au-As-Cu-Pb-Zn anomalies in stream sediments (these possibly related to skarns, Tres Lagunas-type granites or other sources). Occurrences from the Mina Peggy-Río Santa Bárbara-Río Ayllón area southwest through the headwaters of the Río Cuyes to Tutupali, including five >100 grain scheelite anomalies possibly related to Ag-Au-As-Sn-Sb-Cu-Pb-Zn anomalies. This "belt" corresponds with the contact zone of the Tres Lagunas granite batholith and Chigüinda subdivision (Loja division) lithologies, and a series of younger Tertiary and Quaternary intrusives. Pegmatites and/or greisen rocks occur in the Tres Lagunas granite near the headwaters of the Río Cuyes along with young volcanic rocks.

Tungsten in stream sediments are also reported from the Río de la Burra Playa (Principal) and Río Collay (Map 4a), Río Pichinal (east of Saraguro; Map 2f; UNDP, 1972), Malacatus (Map 2d) and San Antonio de las Aradas (Map 2b; Clarke, 1989).

8.3 Tin

Tin mineralization is mentioned in geological map sheets (Ecuador 1:100000 scale) No's 55, and 75 (Appendix B).

Cassiterite and stannite have been reported from the Mina Peggy (de Coster, 1986; Litherland et al., 1990), and cassiterite has been recovered from nearby stream sediments (Clarke, 1989).

Assay values for mineralized samples from Mina Peggy and vicinity (Maps 2h, 4a) range from <20 to 1242 ppm Sn (Appendix D). Clarke (1989) reports similar analyses up to 7684 ppm tin.

Other tin occurrences in the Cordillera Real include: Cassiterite (and scheelite) in pan concentrates from the Río Pichinal (Map 2f) about 11 km east of Saraguro. This anomaly was discovered during a United Nations Development Program survey (UNDP, 1972), and subsequently confirmed during the Cordillera Real project (Clarke, 1989). The cassiterite is likely related to veins, pegmatites or disseminations associated with the nearby S-type Tres Lagunas granite.

A value of 63 ppm Sn is reported for a sample of muscovite-tourmaline "greisen", or pegmatite, from the headwaters of the Río Cuyes (Litherland et al., 1990), also associated with Tres Lagunas granite.

A tourmaline pegmatite from the Monte Olivo "pegmatite belt" of Litherland et al. (1990) gave 33 ppm Sn.

XRF analyses show a Sn peak (see Appendix E) for stream sediments from a tributary of the Río Yacuambí south of the Río Ortega near Tutupali.

No other tin anomalies or occurrences are known, but "greisen" and pegmatite occurrences are known throughout the Cordillera Real. (e.g. Van Thournout and Piedra, 1986; Litherland et al., 1990).

Tin mineralization appears, not surprisingly, to be closely associated spatially with the S-type Tres Lagunas granite and its derivatives. Mineralization at Mina Peggy is also tin-bearing but this mineralization is likely related to Tertiary rhyolite porphyries (see Cu, Pb, Zn section). Curiously, the porphyries and mineralization are, themselves, hosted by Tres Lagunas granite basement.

9. RARE METALS

9.1 Rare Earth Elements

Goossens (1972), reports a possible heavy mineral stream sediment occurrence of thorianite from the Río Verde near Baños.

Litherland et al. (1990) report "strong" XRF peaks (see Appendix E) for caesium, yttrium (and rubidium) in a cluster corresponding with Mo "anomalies" in stream sediments in the Portachuela batholith, near the Peruvian frontier. The three samples reportedly display "strong" peaks for Ce-Y (2 samples) and Ce-Y-Rb respectively. The latter point also corresponds with the highest Nb peak.

A "strong" Ce-Y-Rb XRF anomaly reportedly occurs from a stream sediment sample from the Río Numbala, east of Yangana, and a Ce-Y anomaly occurs at the western headwaters of the Río Cuyes. "Strong" Y-Rb peaks are similarly reported from the Tutupali-Ortega Alto area.

Elevated values of Thorium (27 ppm) and Lanthanum (33 ppm) are reported from a garnet granite sample from Oyacachi, and a sample of vein quartz from the Río Collay yielded 22 ppm Th and 29 ppm La. A value of 38 ppm Th was recorded from a mineralized (polymetallic) vein from the Alao-Palora watershed, and 30 ppm Th from a skarn rock from Sara Urco (Litherland et al., 1990).

All other analysed mineralized samples from the Cordillera Real yielded maximum values of 29 ppm La and 22 ppm Y (Appendix D). Scandium values are usually low (9 ppm max., mostly < 5 ppm; Appendix D).

9.2 Niobium

The only reported occurrences of niobium are "weak" and "moderate" Nb XRF peaks (see Appendix E), corresponding with a cluster of molybdenum peaks, from analyses of stream sediments in the Portachuela batholith near the Peruvian frontier (Litherland et al., 1990).

Anorogenic granites and carbonatites of the types commonly associated with niobium mineralization (Hutchison, 1983) are lacking in Ecuador with a corresponding lack of niobium potential.

10. NON-METALLIC AND INDUSTRIAL MINERALS

10.1 Asbestos

The likely occurrence of fibrous silicates under the general name of "amianto" is discussed by Goossens (1972), who also noted the occurrence of anthophyllite in schists in the Llanganates area.

Small blocks of tremolite asbestos and small veins of antigorite asbestos are commonly associated with the northern serpentinites (Litherland et al., 1990). At the base of the main (Peltetec) serpentinite in the Huarguallá valley (Map 1) there is a 5-metre-thick belt within which slip-fibre chrysotile asbestos is well developed. At higher structural levels the asbestos forms a vein stockwork. Along the Alao road, near Peltetec, loose blocks contain small veins of blue asbestos.

10.2 Barytes/Barium

Barium mineralization is mentioned in geological sheet 72 (Ecuador 1:100000 scale; Appendix B). Wolf (1892) reported baryte from the Pilzhum silver mine near Azogues, and this occurrence has been confirmed. The baryte commonly occurs as fine to coarse platey crystals in epithermal veins.

Anomalous Ba values (Appendix D) have been obtained for samples from other epithermal mineralized locations e.g. Satunsaray-Cuchil (841 ppm), Collay (450 ppm), Loma Quipal (1002 ppm), and Cerro Colorado-Gima (758 ppm; see Gold-Primary Mineralization, and Silver sections). Samples of porphyry-related mineralization also yield Ba values e.g. Mina Peggy (437 ppm), Lomo del Loro (459 ppm), and Cerro Puglla (408 ppm; see Gold-Primary Mineralization, and Silver sections). A value of 1105 ppm Ba was recorded in a sample from the Guarumales polymetallic, volcanogenic massive sulphide prospect (see Cu, Pb, Zn section).

A mineralised mylonitic granodiorite from near La Bonita gave 442 ppm Ba (Litherland et al., 1990).

An "extremely strong" heavy mineral XRF Ba peak (with development of second order peaks; see Appendix E) was noted from a sample upstream from Chicaña, with corresponding vanadium geochemical anomaly (Litherland et al., 1990).

10.3 Carbonates

Carbonate and travertine occurrences are mentioned in geological sheets 56 and 97 (1:100000 scale; Appendix B), and travertine is mined in places e.g. Totoras. The occurrence of travertine is also documented in UNDP (1969b).

Along the sub-Andean belt there are abundant outcrops of Napo Formation black limestone.

A great thickness of marble, blue to off-white in colour, belonging to the Isimanchi subdivision occur on the east bank of the Río Isimanchi, south of Isimanchi, and to the east of Valladolid on the trail to Porvenir.

Accessible marble bands also occur along the Ríos Paute, Zula and Negro, west of Méndez. White marble float blocks occur in the Río Diviso; the Cerro Hermoso black marbles comprise a 500-metre-thick unit. Impure fuchsitic dolomites occur in the Río Cosanga.

In the Huarguallá valley, calcite crystals up to 30×20×20 cm in size can be obtained, but these are not of Iceland Spar quality (Litherland et al., 1990).

10.4 Corundum

Goossens (1972) describes a report by Yantis (1943) of disseminated corundum in an altered syenite located at Ludo about 8 km southeast of San Bartolomé. This occurrence has not been confirmed.

10.5 Diatomite

Goossens (1972) mentions a large deposit of diatomite in Loja, and some other locations. Diatomite occurrences are also recorded on geological map sheets No's 56, 57, and 71 (1:100000 scale; Appendix B).

10.6 Feldspar

Feldspar occurrences are mentioned in geological sheets 75, and 76 (1:100000 scale; Appendix B).

Feldspar-rich rocks include the quartz monzonites and quartz syenites of the Rosa Florida pluton and various microfeldspathic dykes and sheets, aplogranites and aplites. A "well defined" pegmatite belt north from Monte Olivo (Litherland et al., 1990), has, on closer examination, proven to be a belt of semi-pelitic mica schists with occasional bands of quartz-feldspar-muscovite ± tourmaline micropegmatite. Analysis of samples yielded very high silica and the grainsize is usually fine. Micropegmatites of similar mineralogy have been found as far south as the Río Saranan, a tributary of the Río Oyacachi.

It is unlikely that any of the above feldspathic rocks would be of economic interest.

10.7 Fluorite

Fluorite has been described from Cerro de Santa Cruz (Cerro Minas?) near Malacatus (Wolf, 1892; Goossens, 1972). Cerro Minas hosts precious and base-metals mineralization associated with an epithermal intrusive breccia (Map 2d; see Cu, Zn, Pb section). This occurrence has been confirmed and samples of purple fluorite were found associated with vein quartz and as irregular but small masses within a trachyte dyke (Jemielita, 1991b; Appendix F2). Fluorite does not occur in great quantity and is unlikely to be economical.

10.8 Garnet

Garnet is a common mineral over the Cordillera where the local inhabitants sometimes refer to it as "ruby" but no large gem quality garnets have been noted (Litherland et al., 1990).

Garnet rock of high purity is common in the Nambija area and northern skarnfields where they can form bands up to 20 cm thick.

Boulders of red-brown-coloured garnetite were found in the Río Blanco (Chigüinda) and at the confluence of the Ríos Ayllón and Santa Bárbara near Sigsig (Map 4a; Jemielita and Bolaños, 1991a; Appendix F4). The source(s) of these boulders has not been located.

Euhedral, idioblastic, garnets up to 3 cm in size, are present in float blocks in the Río Collanes which drains into the Río Palora from the north (Litherland et al., 1990).

10.9 Gemstones and mineral curiosities

Rutile megacrysts have been reported from the Monte Olivo pegmatites and green euhedral zoisite crystals were described from pegmatised schists east of Monte Olivo (Litherland et al., 1990).

An occurrence of sky-blue lazulite (Fe, Mg-aluminophospate) was found by Van Thournout and Piedra (1986) at the headwaters of the Río Sardinas Chico. Blocks, presumably from this source, have been noted in the Río Quijos below Borja.

Grains of topaz have been recognised in the Cordillera Real heavy mineral study (Litherland et al., 1990). Two occurrences from the headwaters/watershed of the Río Sangurima are located just north of a greisen/pegmatite zone at the headwaters of the Río Cuyes and it is, therefore, likely that this topaz has a greisen source.

Tourmaline (black schorl) is common in pegmatites and in massive quartz veins but tourmaline is only common in the latter veins when they are hosted by sheared Tres Lagunas granite in the Saraguro to Gima areas. Tourmaline occurs in pegmatites at Yangana and along the Monte Olivo pegmatite "belt" of Litherland et al. (1990). No gemstone-quality crystals were noted.

Despite early colonial records referring to emeralds in Ecuador (Navarro, 1986), and the fact that geologically similar conditions exist for the formation of emeralds in the sub-Andean zone of the Oriente, when compared with Colombia (i.e. in contact aureoles of Tertiary intrusives cutting Napo Formation sedimentary equivalents in Colombia e.g. Muzo mines), no occurrences of the gem are known in Ecuador.

Claims for the existence of a lost emerald mine located in the Oriente, north of the Río Aguarico are detailed in a magazine article (Krippene, 1960) and, apparently, supported by a mining claim lodged with the ministry of mines.

A more recent claim of a find of emeralds near the town of Chunchi has been made in the Quito newspaper "La Hora" (Monday 17 February p. 9-10 Tuesday 18 February p. 10, Wednesday 19 February p. 9-10, 1992). The claim is supported by an X-ray diffraction analysis carried out by the Cooperación Geológica Ecuatoriano-Alemana and the "emeralds" are said to occur in a pegmatite associated with quartz, feldspars and other minerals. These claims have not been confirmed geologically.

10.10 Graphite

Graphitic or carbonaceous shales, slates, phyllites and schists are common throughout the Cordillera Real, but no high-grade deposits have been found.

Goossens (1972) lists the occurrences of graphite schists in Ecuador and occurrences are also noted on geological map sheets 56 and 57 (1:100000 scale; Appendix B).

10.11 Gypsum

This mineral is mined locally from the Tertiary rocks of the Malacatus basin, and small occurrences of no economic significance have been noted in basement metamorphic rocks of the Cordillera Real (Litherland et al., 1990). Occurrences of gypsum and anhydrite are detailed on geological map sheets 57, 73, 96 and 102 (1:100000 scale; Appendix B).

Veins of fibrous anhydrite occur in sulphur- and pyrite-mineralized rhyolite breccias at the Shucos (Tixán) sulphur mine (Alausí geological sheet 71; Appendix B).

10.12 Hot springs

The occurrences and chemical compositions of thermal waters in Ecuador are reviewed in Goossens (1972) and de Grys et al. (1970). Thermal waters are also noted on some geological maps (e.g. 1:100000 scale geology sheets 71, 88, and 86; Appendix B).

There is a line of east-draining hot springs east of those shown on the map of de Grys et al. (1970). From north to south these are at Oyacachi, Papallacta, Baños, and El Placer (Río Palora, western headwaters). These springs lie close to the Baños fault and relatively close to the volcanic centres of Cayambe, Antisana, Tungurahua and Sangay respectively (Litherland et al., 1990).

10.13 Kaolin and other clay minerals

The occurrences of kaolin, bentonite and other clays in Ecuador are reviewed by Goossens (1972), together with a list of references. Occurrences of kaolin and other clays are also recorded on geological map sheets (1:100000 scale No's 73, 73NW (1:50000), 75, and 96; Appendix B).

The Azuay-Cañar and Loja sedimentary basins contain numerous deposits of kaolin and bentonite exploited since pre-Spanish colonial times for ceramic manufacture (Goossens, 1972). The clays are associated with acid intrusive and pyroclastic rocks.

Small scale workings for kaolinite were noted in the Shincata-Bestión area (Jemielita 1991b; Map 2g), and small-scale kaolin production has been reported in Puyo and Azogues (Goossens, 1972; Stoll, 1962). The above occurrences are located within volcanic and sedimentary Formations marginal to the metamorphic plutonic basement of the Cordillera Real.

Within the basement, weathered, kaolinitic, feldspar-rich intrusions are common and potential could exist for workable clay deposits (Litherland et al., 1990).

10.14 Magnesite

Small veins of magnesite are common in serpentinites within the Peltetec subdivision and east of the Baños fault, but they are not of economic interest (Litherland et al., 1990). Similar small magnesite veins occur within the Tampanchi layered mafic-ultramafic intrusion.

Other occurrences of magnesite in Ecuador are noted in Goossens (1972).

10.15 Mica

Ribadeneira (1960) mentions general areas for the occurrence of biotite and muscovite.

Small one or two-mica pegmatites are found along the cordillera, but crystals are a maximum 5 cm across and of no economic interest.

10.16 Ornamental stone

Many new occurrences with ornamental stone potential have been discovered in the Cordillera Real (Litherland et al., 1990). These include the blue quartz-feldspar granites of Tres Lagunas; the "black granites" (megacrystic gabbros) of Tampanchi; the pink syenites of Rosa Florida; the green/pink/black northern skarnfield rocks; serpentinites (green and black); pale or black marbles; and many granitoid plutons (Litherland et al., 1990).

Orbicular diorite boulders have been observed in the Río San Miguel near Monte Olivo (Map 7a; Jemielita and Bolaños, 1992b; Appendix F7), but the source of these boulders has not been traced.

Travertine is widely used as a building and ornamental stone in Ecuador. Travertine occurrences are mentioned in geological sheets (1:100000 scale; Appendix B) No's 55, 71, 73, 73NW, and 100.

10.17 Phosphate rocks

The occurrence and economic potential of phosphate rocks in Ecuador have been reviewed by Wilkinson (1982) and Boujo et al. (1984). The most significant areas of phosphate potential lie east of the Cordillera Real within lithologies of the Cretaceous miogeosynclinal Napo Formation of the Oriente.

An apatite-rich metagranite collected east of Papallacta gave 2.25% P_2O_5, but this has no economic significance (Litherland et al., 1990).

Phosphate occurrences are also shown on geological map sheets No's 88, 98, 99, 100, and 102 (1:100000 scale; Appendix B).

10.18 Quartz and silica minerals

Quartz occurs in the Cordillera Real as rock crystal and massive vein quartz but no potentially commercial deposits are known. Quartzites of the Hollín Formation (Cretaceous), which outcrop along the sub-Andean zone east of the Cordillera Real, could have economic potential for glass manufacture and some workings are reported in the vicinity of Limón and Indanza (pers. comm. J. Aspden, 1993). Litherland et al. (1990) noted pure Hollín Formation quartzites outcropping along the right bank of the Río Chuchumbleza.

Hollín Formation quartzites are mentioned in geological map sheets No's 87, 98, 99, 100, 101 and 102 (1:100000 scale; Appendix B). Other silica mineral occurrences, e.g. geyserite, opal and jasper, are noted by Goossens (1972) and Ribadeneira. (1960).

10.19 Sillimanite minerals

Both sillimanite and kyanite have been noted in the Cordillera Real but their occurrence is of academic interest only (Litherland et al., 1990).

10.20 Sulphur

Along the western flanks of the Cordillera Real deposits and indications of native sulphur are invariably associated with young volcanic rocks.

The past producing Shucos mine at Tixán contains native sulphur associated with rhyolite lavas and breccias. The rhyolites are sometimes pyritized and geyserite has been noted in the mine area (Goossens, 1972; Zamora, 1985).

The nearby Chunchi district is characterised by extensive, and often intensive, hydrothermal alteration of andesitic volcanic rocks (Alausí geological sheet 71; Appendix B). Disseminated pyrite occurs in places and the area is said to contain native sulphur mineralization.

Minor amounts of native sulphur, associated with zones of pyritic alteration, are present within Tarqui Formation volcanic and volcaniclastic lithologies between Atillo and Laguna Atillo (Map 5b).

At Malacatus, near Loja, Goossens (1972) reports sulphur and gypsum impregnations in a coal seam. Other occurrences of sulphur in Ecuador are documented in Goossens (1972), and in geological map sheets No's 71, 96 and 97 (1:100000 scale; Appendix B).

10.21 Talc

Some talc (and steatite) showings in the Cordillera Real are described in Ribadeneira (1960). Talc schists and talcose serpentinites are said to be commonly associated with serpentinite bodies but no large deposits were noted (Litherland et al., 1990). Occurrences of talc are noted on geological map sheets No's 72, 88, 87 and 90 (1:100000 scale; Appendix B).

11. ENERGY MINERALS

11.1 Coal

Coal reserves occur in the Miocene Cuenca, Loja and Malacatus basins (Stoll, 1962; UNDP, 1969a), but not in the basement rocks.

Coal and/or lignite occurrences are mentioned in geological map sheets No's 55, 56, 57, 73, 73NW (1:50000), 75, 87, 101, and 102 (1:100000 scale; Appendix B).

11.2 Oil

Asphalt occurrences are mentioned in geological map sheets No's 101, and 102 (1:100000 scale; Appendix B). The geology and early oil exploration in the sub-Andean zone and Oriente were reviewed in a classic paper by Tschopp (1953).

Bituminous black shales; probably derived from the Napo Formation, which when hammered give a smell of petroleum, have been found as river blocks in the Río Chingual, Río Salado and Río Vergel. Mudstones from the Tertiary Malacatus basin gave a total hydrocarbon yield of 60-80 kg/tonne (Litherland et al., 1990).

11.3 Uranium

Uranium occurrences are mentioned in geological map sheets No's 100, 101, and 102 (1:100000 scale; Appendix B).

A 30 cm band of uraniferous phosphate was reported by Vera (1980) from the Río Chingual near the Colombian border. A project field scintillometer survey confirmed the radioactive anomaly (320 c.p.s.).

A value of 19 ppm U was recorded from a copper-mineralized gneissic block in the Río Condué, and 13 ppm from a tourmaline pegmatite from the Monte Olivo belt SE of San Gabriel.

Most field samples including those from pegmatites, have been examined in the office under a portable gamma ray scintillometer, but no anomalously high counts have been noted.

Various weak radiometric anomalies, mostly below 300 c.p.s., were determined from the metamorphic rocks during the national uranium survey (Carrión and Villalba, 1981; Severne et al., 1978). Some relate to small Cu mineralisations in the Zamora batholith along the Zamora-Cumbaratza road, others were found along the Río Paute between Amaluza and Méndez. Uranium stream sediment anomalies up to 5 ppm were detected in the Río Jamboe, east of Zamora batholith. Uranium anomalies were also found in the freshwater Miocene sediments of the Cuenca, Loja and Malacatus basins (Litherland et al., 1990).

12. MINERAL POTENTIAL AND METALLOGENESIS OF THE CORDILLERA REAL OF ECUADOR

12.1 Mineral potential

The Cordillera Real of Ecuador forms part of a 650 km long segment of the Pacific Rim, a global feature of outstanding mineralization and mineral potential. Recent geological studies in Ecuador have revealed a history of subduction, tectonic accretion and transpression since the Triassic (Aspden and Litherland, 1992; Litherland and Aspden, 1992). These features are remarkably similar to those described in other Pacific Rim regions. The similarities are reinforced by comparison of the metallogenesis of Ecuador with better known areas such as Alaska (Goldfarb et al., 1986), and British Columbia (McMillan et al., 1986).

A metallogenic classification of the Cordillera Real can be made by correlation of mineralization with host lithologies, structures and ages of the host rocks. Examination of these correlations also permits the construction of a metallogenic history for the region, and predictions regarding the mineral potential of the Cordillera Real.

The most potentially economic types of mineralization in the Cordillera Real and adjacent areas are considered below:

12.1.1 Volcanogenic massive sulphide (VMS) mineralization

On a worldwide scale, volcanogenic massive sulphide deposits are important producers of base metals, with significant by-product precious metals and other elements. These deposits are attractive exploration targets in Pacific Rim accretionary terrane margins such as Alaska (Goldfarb et al., 1986), and British Columbia (McMillan et al., 1986).

Two polymetallic VMS deposits (Macuchi, La Plata) have previously been worked in the Western Cordillera of Ecuador, and at least two further examples (Mina Pilas and Guarumales) have now been identified in the Cordillera Real (Jemielita, 1991a; Jemielita and Bolaños, 1991a; see Gold-Primary Mineralization and Cu, Pb, Zn sections).

At Mina Pilas, massive, granular and bedded pyrite, is interbedded with greenschist and sericite schist meta- volcanic rocks of the Jurassic Alao-Paute subdivision. The massive pyrite contains only anomalous gold (479 ppb; see Gold-Primary Mineralization section), but the deposit is a volcanogenic massive sulphide and is a very encouraging indication for potential polymetallic (Cu-Zn-Pb ± Au ± Ag) VMS mineralization elsewhere within the Alao-Paute subdivision.

A reported occurrence of strong sulphide mineralization at Cerro Soroche (Cruz, N.D.) to the south of Mina Pilas, also lies within lithologies of the Alao-Paute subdivision, and may be another exposure of VMS-type mineralization.

At Guarumales, on the Río Paute, mineralized schists and massive polymetallic sulphides are exposed within chlorite, sericite and graphitic schists of the Jurassic Upano subdivision. Analyses show high or anomalous values of Au, Ag, Cu, Pb, Zn, Cd, As, Sb, Mo, W and Ba. Guarumales is a deformed and metamorphosed, polymetallic (Kuroko-type?), volcanogenic massive sulphide deposit (Hutchinson, 1980).

Polymetallic VMS deposits usually occur in rifts within island arcs associated with bimodal calc-alkaline volcanism. The greenschist metavolcanic-dominated Alao-Paute subdivision and Upano subdivision lithologies are geochemically of oceanic island arc composition (pers. comm. J. Aspden, 1993). These lithotectonic subdivisions occupy large areas of the Cordillera Real and are highly prospective for volcanogenic massive sulphide deposits.

12.1.2 Mineralized skarns

Skarn mineralization is a common feature of Pacific Rim accretionary terrane margins such as Alaska (Goldfarb et al., 1986), and British Columbia (McMillan et al., 1986).

In Ecuador, interest in skarn mineralization has resulted from the recent rediscovery of the Nambija gold skarns in the south east of the country.

The auriferous skarn deposits, typified by Nambija, occur within a Triassic volcano-sedimentary roof pendant perched on the Jurassic Zamora batholith (see Gold-Primary Mineralization section). Production is dominated by gold, and up to 30 tonnes is estimated to have been produced at Nambija alone since 1982.

Granodiorite-diorite batholiths of similar age and composition as the Zamora batholith occur further north along the eastern side of the Cordillera Real e.g. Abitagua batholith, La Bonita pluton, Rosa Florida pluton. Potential for skarn mineralization also exists in these areas e.g. epidotized and pyritized, indurated/hornfelsed, banded, fine-grained sediments occur within the La Bonita pluton (Jemielita and Bolaños, 1992b; Appendix F7).

The existence of skarns, interpreted as isolated klippen, along the watershed of the Cordillera Real has been documented, and anomalous values of Au, Ag, Cu, Pb, Zn, and Mo have been reported from these lithologies (Litherland et al., 1990). Formation of the skarn klippen is attributed to dynamic and thermal metamorphism of Triassic-Jurassic sedimentary and volcanic lithologies during thrusting over the cooling Middle-Jurassic Azafrán batholith. These skarns constitute considerable potential tonnages of material and could repay more detailed investigation.

The ages of (Jurassic) intrusive and (Triassic) skarn host lithologies in Ecuador are strikingly similar to some deposits in British Columbia, e.g. Hedley (McMillan et al., 1986), and Alaska, e.g. Wrangell Mountains (Goldfarb et al., 1986).

The large areal extent of the Zamora batholith and other areas of potentially mineralized skarns within the Cordillera Real, together with the rugged and inaccessible nature of the terrain, provides considerable potential for further discoveries of economic skarn mineralization in Ecuador.

12.1.3 Granodiorite intrusion-related mineralization

I-type granitoids are often associated with major sulphide mineralization and S-type granitoids are commonly associated with tin and tungsten mineralization (Ishihara, 1981). Both I-type and S-type granitoids occur in the Cordillera Real of Ecuador (Aspden and Litherland, 1992), and are associated respectively with sulphide and Sn-W mineralization.

The Triassic Tres Lagunas granite has mineralogical and geochemical characteristics of S-type granites but only weak occurrences of tin and tungsten mineralization are associated with this intrusion.

The majority of plutonic granitoids within the Cordillera Real are I-type in character and range in age from Jurassic to Middle-Tertiary. In places, these granitoids are associated with precious and base metals mineralization, particularly within the Zamora batholith (see Skarns section above).

Within the central area of the Cordillera Real, high level porphyritic intrusions are generally rare or absent. This may be a result of deep erosion due to tectonic uplift. Deeper level intrusions such as batholithic granites and granodiorites occur but, in places, small granular granodioritic plutons exist. These plutons are often mineralized and have mineralized their country rocks. A prominent suite of granodiorite plutons outcrops from the Río Ishpingo (Map 4a) to the Río Salado (Map 5a) and one example (Amaluza; Map 4b) was dated at 41.9 Ma (K-Ar). The altered and mineralized intrusions and their host rocks represent huge potential tonnages of mineralized rocks and anomalous values of Au, Ag, As, Cu, Zn and Mo have been recorded (Appendix D).

These intrusions may represent the deeper levels of mineralized porphyry systems and warrant further investigation.

12.1.4 Porphyry-related disseminated, breccia and vein mineralization

The worldwide importance of porphyry copper deposits, and other porphyry-related types of mineralization, reflects the large tonnages of metals amenable to economic exploitation contained within these types of mineralization (Titley and Beane, 1981). The greatest concentration of porphyry copper deposits and associated mineralization occurs around the Pacific Rim, especially in Chile (Sillitoe, 1993).

Porphyry-related mineralization occurs along the western flank of the Cordillera Real of Ecuador where young Tertiary volcanic rocks lap onto metamorphic and plutonic basement. The regional scale Las Aradas-Baños fault system seems to be a particularly important structural control on this type of mineralization (see Structural Controls on Gold-Silver Mineralization section). Mineralization ranges in character from disseminated sulphides and stockworks, to intrusive breccias and discrete veins, and is usually polymetallic (Au, Ag, Cu, Pb, Zn, Mo, and other metals), and mesothermal to epithermal in character. Mineralization is closely associated spatially and temporally with small, Middle- to Upper-Tertiary granodiorite, dacite and rhyolite porphyry intrusions.

The porphyry intrusions and associated mineralization are a manifestation of subduction-related magmatism controlled by major structures such as the Las Aradas Baños fault. This structure, and other parallel faults along the western margin of the Cordillera Real, are highly prospective for porphyry-related mineralization.

12.1.5 Volcanic-hosted epithermal mineralization

Epithermal deposits are an important source of gold and silver and have been the target of aggressive exploration worldwide, but especially around the Pacific Rim, since the early 1980's (Mitchell and Leach, 1991; Sillitoe, 1983).

In Ecuador, epithermal silver-gold mineralization is relatively common within andesitic to dacitic porphyry volcanic and volcaniclastic rocks and many features common to epithermal-type precious metal environments (White and Hedenquist, 1990), have been recognized.

San Bartolomé is a silver-rich, polymetallic, epithermal vein deposit, and similar deposits at Pilzhum (Ag) and, possibly, Cubillín (Ag) and Tungurahua (Ag), emphasize the silver-rich nature of this mineralization. The mineralogy and textures observed in these vein deposits are typical of the deeper epithermal (bonanza lode) environment.

Acid-leached and silicified epithermal porphyry breccias are sometimes associated with gold or silver and barium anomalies e.g. at Cerro Minas (Gima) and Río Pilares (Collay). Chalcedonic and opaline silica occurs with silicified and pyritized porphyry breccias at Cuchil near Sigsig. Up to 4 g/T Au has been assayed from opaline breccia. Silicified, alunite-veined and argillically-altered volcanic rocks occur at Loma Quipal, also near Sigsig. At Tixán and Chunchi, extensive areas of volcanic and volcaniclastic rocks are strongly hydrothermally altered and pyritized. Sulphur has been produced at Tixán and noted at Chunchi. Strong pyrite mineralization, mostly disseminated, in volcanic and volcaniclastic rocks is characteristic of Principal, and Cerro Pucurcu Grande (and Chico?) -Atillo. Epithermal mineralization related to sericite, alunite and silicification is also reported from the vicinity of Saraguro.

Volcanic-hosted epithermal mineralization mostly occurs within Tertiary (Oligocene to Quaternary), andesitic to rhyolitic, volcanic and volcaniclastic lithologies of the inter-Andean graben and displays a strong spatial association with the Las Aradas-Baños fault and parallel structures on the west flank of the Cordillera Real.

12.1.6 Shear zone-hosted mesothermal vein mineralization

Mesothermal vein mineralization is usually hosted by shear zone structures, and is typical of Archaean greenstone environments (Colvine et al., 1988), and Phanerozoic transpressional convergent margins, especially around the Pacific Rim e.g. Alaska (Goldfarb et al., 1987), British Columbia (McMillan et al., 1986; Nesbitt and Muehlenbachs, 1988), California (Bohlke and Kistler, 1986), and New Zealand (Craw, 1992). This type of mineralization has not previously been widely recognized or documented in Ecuador or, indeed, in South America.

In Ecuador, massive, mesothermal quartz veins are ubiquitous throughout the schistose lithologies of the Ecuadorian Cordillera Real, and boulders of massive vein quartz occur in almost all of the rivers examined.

The quartz veins are, likely, concentrated in Andean-trending, regional-scale, high strain, brittle-ductile shear structures, but this is only obvious along the Las Aradas-Baños fault system.

At Cera, near Loja, gold is extracted from massive quartz-ankerite-pyrite veins which cut grey-black carbonaceous mica schists along the Las Aradas fault (shear zone). Similar mineralization occurs near Yangana, at Masanamaca and, reportedly, east of Loja (Wolf, 1892). Apart from these localities no other occurrences of primary gold mineralization of this type are known in the Cordillera Real. Nevertheless, the widespread occurrence of this type of vein material in gold-bearing rivers suggests a genetic connection. This is supported by the composition of boulders in the auriferous palaeo-placer deposits of Shincata-Bestión, and the Tena and Tiyuyacu Formation sediments (see Palaeoplacers section), which contain a high proportion of massive vein quartz and, in the case of Shincata-Bestión, black tourmaline pebbles of hydrothermal origin.

The shear zones which host mesothermal quartz veins in the Cordillera Real likely had an extended kinematic history between 226 Ma (U-Pb zircon age - Tres Lagunas Granite) and 60 to 80 Ma (K-Ar closure temperature of main metamorphic peak in the Cordillera Real - possibly representing accretion of the Chaucha terrane). The mesothermal quartz vein mineralization may have occurred episodically between these dates.

Mesothermal vein mineralization is thought to have formed at crustal depths of between 2 km and 10 km (Colvine et al., 1988), but a large degree of tectonic uplift in the Cordillera Real may have eroded the auriferous quartz veins below the (2 km to 10 km depth) window of mineralization. This is supported by the large volumes of mesothermal vein quartz boulders in the auriferous Tena, Tiyuyacu and other sedimentary Formations located marginal to the Cordillera Real.

Mesothermal quartz-gold vein mineralization, and its erosional products, have been a significant source of world gold production, especially around the Pacific Rim, but the potential for economic primary mineralization of this type in the Cordillera Real of Ecuador is considered to be low.

12.1.7 The Las Aradas-Baños Fault

The Las Aradas-Baños fault system is a major Andean-trending structure that generally corresponds with the contact between Tertiary volcanic and volcaniclastic rocks of the inter-Andean graben and metamorphic-plutonic lithologies of the Cordillera Real basement in Ecuador (Figure 2). In southern Ecuador, a deflection in this structure appears to control several types of precious and base metals mineralization, including mesothermal quartz (± gold) veins, volcanic-hosted epithermal and porphyry-related gold-silver mineralization, and alluvial gold deposits (Figure 7).

The Las Aradas-Baños fault is a fundamental crustal structure, possibly representing a terrane suture (Litherland and Aspden, 1992). The fault system continues northwards into Colombia, where it is known as the Romeral fault, and forms the western boundary of the central Cordillera (Aspden et al., 1987). The Central Cordillera of Colombia hosts the most important primary gold mineralizations in the country, and has the highest resource potential for gold (Utter, 1984).

The Las Aradas-Baños-Romeral fault system is at least 2000 km long and has a strong spatial and, possibly, genetic connection with several different styles of gold mineralization.

Tensional sections of the fault, such as jogs or fault deflections (e.g. Saraguro-Sigsig section of the Baños fault), are particularly prospective for mineralization.

12.1.8 Paleoplacer gold deposits

World class alluvial gold deposits occur around the Pacific rim including most of the Andean countries of South America (Henly and Adams, 1979), but Ecuador is a notable exception.

In Ecuador, alluvial gold is commonly worked in active river sediments and incised terraces marginal to the rivers (see alluvial deposits section). These deposits are usually small in volume and the sediments are very immature. However, substantial deposits of potentially auriferous quartz pebble conglomerates exist and these deposits display similarities to the Witwatersrand-type quartz pebble gravels or conglomerates and similar deposits (Pretorius, 1981).

Unconsolidated and semi-lithified conglomerates and gravels comprising quartz pebbles of mesothermal vein origin occur along the western flank of the Cordillera Real and, more extensively, in the sub-Andean zone. The latter deposits occur as mature (vein) quartz pebble gravels, within the Tena Formation and, especially, the Tiyuyacu Formation sediments exposed in the sub-Andean zone east of the Cordillera Real (Sauer, 1965). These Formations can reach strike lengths of up to 150 km (Baldock, 1982), and gold is sometimes worked directly from these beds. It is also interesting to note that the Ríos San Miguel, Aguarico, Coca, Payamino, Napo, and Cushimi are not notably auriferous upstream of exposures of these beds (Figure 4a, b, c). This is especially true of the Río Payamino which does not appear to have any direct connection with the Cordillera Real. It is likely that the quartz pebbles and gold were derived from erosion of Cordillera Real mesothermal veins and that the sediments are now being reworked. The extensive exposure of these auriferous sediments indicates immense potential tonnages of gold-bearing material.

In the Río Shincata-Río Betas area southeast of Nabón, gold is extracted from terrace gravels which cover a large area of relatively level ground on the western slope of the Cordillera Real. The terraces comprise moderately to well-sorted and bedded (vein) quartz-pebble gravels which contain some rounded black tourmaline pebbles and fine-grained gold. These sediments are relatively mature and unlithified and their composition indicates a mesothermal auriferous quartz-tourmaline vein source. Such veins occur in basement schists in the vicinity.

The conglomerates and gravels are mature sediments comprising resistate minerals i.e. quartz, chert, tourmaline and gold and likely formed due to reworking and/or strong weathering and erosion of the less resistant minerals and rocks. Deep lateritic soil horizons occur in places at altitude in the Cordillera Real where relict textures indicate granitoid and schist pre-cursor lithologies but vein quartz is preserved (e.g. Río Shincata-Mina Rea; map 2g; Jemielita, 1991b; Appendix C2).

The bulk of the quartz pebble conglomerates occur along the east flank of the Cordillera Real where they appear to contribute substantially to the gold budget of the east-flowing major rivers in the upper Amazon basin (Oriente). These deposits indicate a very considerable erosion of the Cordillera Real especially in the late Cretaceous (Tena Formation) to Palaeocene-Eocene time (Tiyuyacu Formation). This corresponds temporally with accretion of the Chaucha terrane to the west.

Quartz pebble gravels of the Bestión Formation overlie young volcanics (Pliocene-Pleistocene Tarqui Formation?) and may be related to recent glacial episodes.

12.1.9 Alluvial gold deposits

Historically, alluvial gold deposits were probably the earliest targets for human exploitation and continued to be attractive throughout the classical "goldrushes" of the 19th century and, indeed, to the present day. These deposits are attractive, especially to artisanal miners, because they are relatively easy to exploit. Alluvial gold deposits have yielded a substantial proportion of world gold production, especially from "world class" placer fields, mostly located around the Pacific Rim (Henly and Adams, 1976). Ecuador is bounded by Peru and Colombia, both of which have "world class" alluvial gold placers.

In Ecuador, gold is worked in active river sediments and incised river terraces in many rivers in the Cordillera Real. These alluvial deposits are generally narrow and elongate (Pillajo and Báez, 1983), and occupy steeply incised river valleys. The volume of auriferous material is usually small and the sediments are polymict and very immature. Large boulders (several metres in diameter) are common, and only artisanal methods are used to extract gold. It is unlikely that large scale commercial dredging operations would be economical in these areas under present conditions. Away from the steep slopes of the Cordillera, flatter terrace areas are sometimes auriferous. The Río Palora-Río Sangay area is characterised by wide terraced valleys and gold is worked from the polymict terrace gravels (Map 8a). The gravels generally appear to lack very large boulders and cover several square kilometers. An extensive horizon of volcanic lahar underlies the alluvium and provides a "false bed" to the auriferous gravels. The area would probably support a dredging operation but any commercial exploitation is likely to be hampered by the National Park status of the region.

Extensive alluvial terrace and active alluvial gold deposits also occur in the region around Tena.

The origin of the gold in the alluvial river and terraces is attributed largely to mesothermal shear zone-hosted quartz veins (Jemielita and Bolaños, 1992). This is supported by the generally high-fineness values for Cordilleran alluvial gold (Wolf, 1892; Morrison et al., 1991), however, other primary gold sources cannot be ruled out and this is supported by limited studies on alluvial gold fineness (Beddoe-Stephens, 1987, 1989), which have revealed some silver-rich alluvial gold in places. The high Ag/Au ratios of many primary mineralizations in the Cordillera Real (e.g. Mina Peggy-Río Ayllón, Guarumales, Pilzhum/San Bartolomé), indicate likely sources for silver-rich alluvial gold.

12.2 Metallogenic history of the Cordillera Real of Ecuador

The earlier geological history of the Cordillera Real is dominated by subduction-related magmatism, terrane accretion, and transpressional tectonics, resulting from variations in plate convergence geometries between the Pacific oceanic plate(s) and northern continental South America (Aspden et al., 1987; McCourt et al., 1984).

The metallogenic history of the Cordillera Real, and adjacent areas, closely follows the geological history of the region as summarised in Figure 8.

Sn-W mineralization is related to intrusion of the S-type Tres Lagunas granite batholith (Triassic 226 Ma) and associated lithologies, during a rifting phase on the Gondwanaland continental margin.

Subsequent terrane collision of the Chaucha plate was followed by dominantly dextral transpression resulting in, probably episodic, shear zone-hosted, mesothermal vein quartz-Au mineralization along terrane sutures and other faults, especially the Las Aradas-Baños fault, between 220 Ma and 60 Ma.

Jurassic (190-150 Ma) oceanic island arc rift basins were sites of volcanogenic massive sulphide mineralization (Alao-Paute and Upano subdivisions) subsequently accreted to the continental edge about 140 Ma ago.

Subduction-related Jurassic Zamora batholith I-type diorite-granodiorite batholith generated skarn mineralization in Triassic volcano-sedimentary roof pendants around 190 Ma. This intrusive episode may also have generated gold-skarn mineralization.

Early-Tertiary (60 Ma) ultramafic intrusions sometimes generated platinum group metals, chromium, nickel and, possibly, gold mineralization.

During the Tertiary, subduction-related magmatism and associated mineralization prevailed in the Cordillera Real and other parts of Ecuador.

Early to Middle Tertiary (ca. 40 Ma) granodiorite plutons generated disseminated sulphide mineralization within their outer margins and adjacent country rocks.

Minor Cretaceous and major Middle-Tertiary (Eocene) weathering and erosion of the Cordillera Real produced relatively pure (mesothermal vein) quartz pebble gravels (Tena Fm. and Tiyuyacu Fm. respectively) containing alluvial gold. Deposits occur mostly to the east of the Cordillera Real along the sub-Andean zone.

Late Tertiary porphyry-related polymetallic mineralization occurred along the western margin of the Cordillera Real, especially along the Las Aradas-Baños fault and parallel structures. In overlying and comagmatic volcanic and volcaniclastic lithologies epithermal Ag-Au mineralization was generated.

Throughout the Tertiary to Recent times alluvial gold deposits have formed by erosion of primary gold mineral deposits within the basement lithologies of the Cordillera Real.

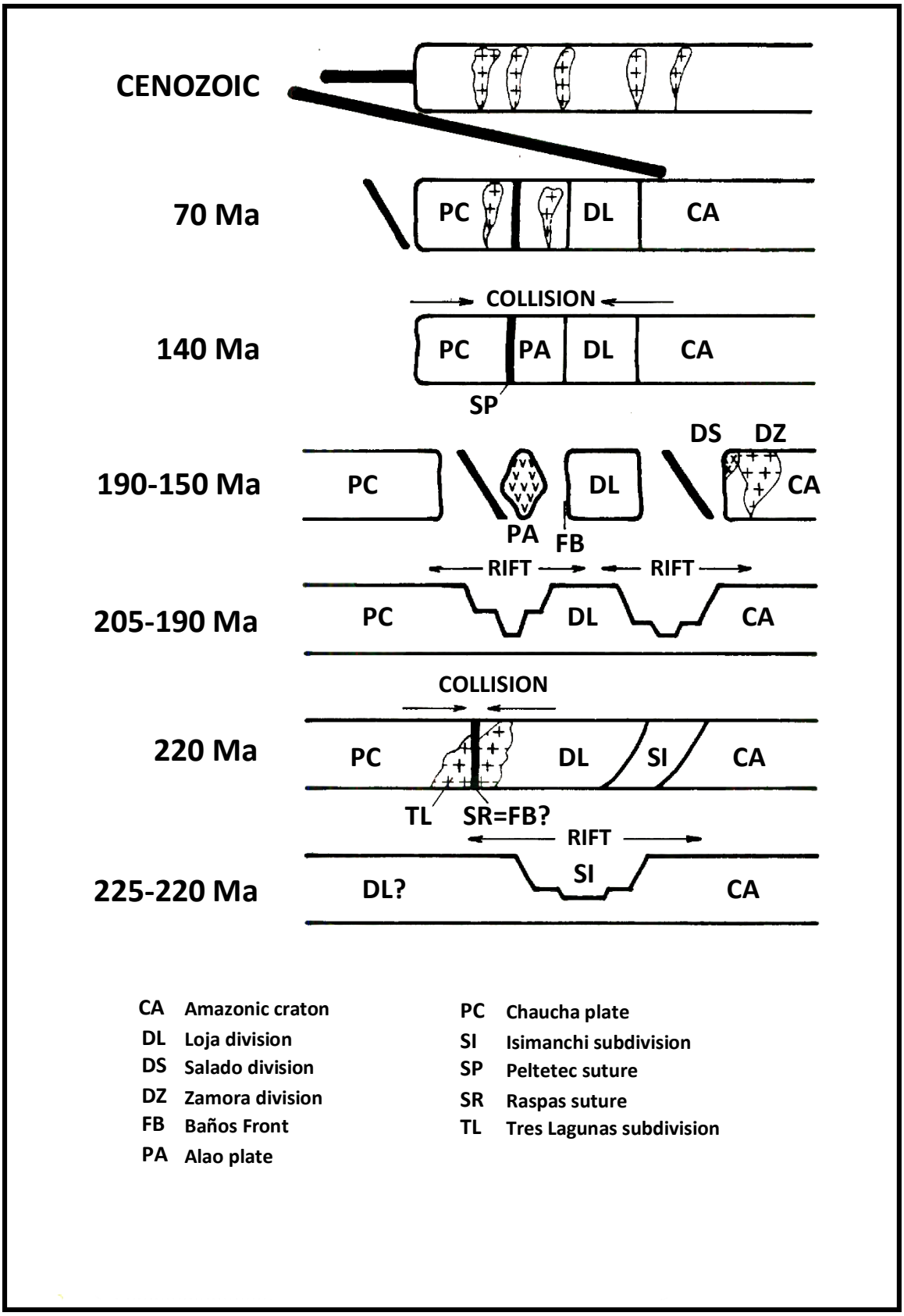

Figure 8. Diagram of the geological history of the Cordillera Real of Ecuador (after Litherland et al., 1990).

12.3 Pacific-Rim mineralization and the Mineral Potential of the Cordillera Real of Ecuador

The Cordillera Real of Ecuador has similar geological, chronological, mineralogical and metallogenic features to other Pacific Rim regions e.g. Alaska (Goldfarb et al., 1987); British Columbia (McMillan et al., 1987), California (Bohlke and Kistler, 1986), Colombia (Aspden et al., 1987), Peru and Bolivia (Sillitoe, 1993; Fornari and Herail, 1991); and New Zealand (Craw, 1992).

Many of these regions have similar lithotectonic compositions and Mesozoic-Cenozoic accretionary/collisional histories at converging oceanic-continental plate margins, and this is reflected in their similar mineral deposit inventories.

Typical mineralization includes oceanic island arc-derived volcanogenic massive sulphide deposits; subduction-related magmatic hydrothermal deposits (porphyry-related mineralization; volcanic-hosted epithermal mineralization); and shear zone-hosted, auriferous, mesothermal quartz veins or lodes. The latter mineralization is also, likely, responsible for the common occurrence of giant gold-placer fields around the Pacific-rim (Henly and Adams, 1979), including many of the above regions.

From a current economic perspective, the most prospective types of mineralization now known in the Cordillera Real and adjacent areas are:

i) Polymetallic volcanogenic massive sulphides.

ii) Gold-skarn mineralization.

iii) Polymetallic porphyry-related mineralization.

iv) Volcanic hosted, epithermal, precious metals mineralization.

v) Auriferous quartz pebble conglomerates or gravels.

Successful exploration strategies may be devised for the Cordillera Real, and other areas in Ecuador, based upon the known occurrences of mineral deposits in the better explored and exploited regions around the Pacific Rim.

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APPENDIX A

List of available topographic sheets

Table 1. List of available 1:50000 scale topographic sheets (to end 1992) published by I.G.M., and covering the Cordillera Real of Ecuador.

Sheet N°	Name	Edition	Sheet N°	Name	Edition
CT-ÑV-A3.3887-III	Alausí	1	CT-OII-D3	La Palmera	1
CT-NVII-D3.3780-III	Amaluza	1	CT-NVI-F4.3782-II	Loja Norte	2
CT-ÑIV-A4.3890-II	Ambato	1	CT-NVI-E2.3882-I	Los Encuentros	1
CT-ÑV-E1.3885-IV	Azogues	1	CT-OII-A2	María Magdalena	1
CT-OIII-C1	Baeza	1	CT-OII-E1.4094-IV	Mariano Acosta	1
CT-ÑIII-B2.3993-I	Cangahua	1	CT-NVI-D2.3783-I	Nabón	2
CT-ÑV-C3.3886-III	Cañar	1	CT-NVII-B1.3781-IV	Nambacola	1
CT-ÑVII-A4.3681-II	Cariamanga	2	CT-OII-E3.4094-III	Nevado Cayambe	1
CT-NVII-A2	Catacocha	1	CT-OIV-E3.4088-III	Nueva Huamboya	1
CT-NVI-F3.3782-III	Catamayo/La Toma	3	CT-ÑII-B4.3993-II	Oyacachi	1
CT-ÑII-F4	Cayambe	1	CT-ÑV-A2.3887-I	Palmira	1
CT-OIII-A1	Cerro Saraurcu	1	CT-OIV-E1.4088-IV	Palora	1
CT-ÑV-C4.3886-II	Cola de San Pablo	1	CT-ÑVI-C4.3883-II	Pangui	1
CT-ÑVII-A3.3881-III	Cord. de Tzunantza	1	CT-ÑIII-D2	Papallacta	1
CT-OIII-C3.4092-III	Cosanga	1	CT-ÑVI-E4.3882-I	Paquisha	1
CT-ÑIII-F1.3991-IV	Cotopaxi	2	CT-OII-C3.4095-II	Pimampiro	1
CT-NV-F4.3785-II	Cuenca	1	CT-ÑIII-D1.3992-IV	Píntag	2
CT-ÑV-E3.3885-III	Gualaceo	1	CT-OII-F1	Puerto Libre	1
CT-OIII-D1.4195-IV	El Calvario	1	CT-OIV-A2.4090-I	Puerto Misahuallí	1
CT-NVI-B2.3784-I	Girón	2	CT-OIV-A1.4090-IV	Puerto Napo	1
CT-NVII-B3.3781	Gonzanamá	2	CT-OIV-C1	Puyo	1
CT-ÑV-E2.3885-I	Guachapalá	1	CT-ÑIV-C2.3889-1	Quero	1
CT-ÑV-E3.3885-III	Gualaceo	1	CT-ÑIII-B3	Sangolquí	1
CT-ÑIV-E4.3888-II	Guamote	1	CT-ÑIV-E2.3888-I	Riobamba	1
CT-ÑIV-C4.3889-II	Guano	1	CT-NVII-F3	Río Blanco	1
CT-ÑVII-A2.3881-I	Guaysimi	1	CT-NVII-C2.3680-I	Río Calvas	2
CT-OII-C2.4095-I	Huaca	1	CT-ÑIII-F4	Río Chalupas	1
CT-ÑV-C2.3886-I	Huangra	1	CT-OII-E2	Río Cofanes	1
CT-ÑII-D4.3995-II	Ibarra	1	CT-OII-E4	Río Due Grande	1
CT-ÑV-C1.3886-IV	Juncal	1	CT-NVII-F2.377-I	Río Mayo	2
CT-NVII-F1.37 -IV	Laguna Cox	1	CT-ÑIV-B2	Río Mulatos	1
CT-ÑIII-F3.3991-III	Laguna de Anteojos	1	CT-NVII-B2.3781-I	Río Sabanilla	2
CT-ÑIII-D4.3992-II	Laguna de Micacocha	1	CT-ÑIV-A2.3890-1	Salcedo	1
CT-ÑIII-E4	Latacunga	1	CT-NVI-F1.3782-IV	Santiago	3
CT-NVI-F3.3782-III	La Toma	2	CT-NVI-D4.3783-II	Saraguro	2
CT-NVII-D1.3780-IV	Las Aradas	2	CT-OIV-F1.4188-IV	Sarayacu	1
CT-OII-C4	La Bonita	1	CT-OIII-E1.4091-IV	Sardinas	1
CT-NVI-F2.3782-I	Las Juntas	2	CT-NVI-D3.3783-III	Selva Alegre	3
CT-OIII-A4.4093-II	Las Palmas	1	CT-ÑVI-A1.3884-IV	Sigsig	1

Table 2. List of available 1:25000 scale topographic sheets (to end 1992) published by I.G.M., and covering the Cordillera Real of Ecuador

Sheet N°	Name	Edition
CT-ÑIV-D1a.3989-IVNW	Baños	1
CT-ÑVI-D3c.3989-IIISW	Cerros Negros	1
CT-ÑIV-F1a.3988-IVNW	Laguna Pintada	1
CT-OII-E3a.4094-IIINW	Laguna San Marcos	1
CT-ÑV-B1c.3987-IVSW	Laguna de Tinguichaca	1
CT-ÑIV-B3c.3990-IIISW	La Joya	1
CT-ÑIV-B3d.3990-IIISE	Los Llanganates	1
CT-ÑIV-D3a.3989-IIINW	Palitahua	1
CT-ÑV-B3a.3987-IIINW	Purshi	1
CT-ÑV-B3c.3987-IIISW	Río Abanico	1
CT-ÑIII-F2b.3991-INE	Río Antisana	1
CT-OIII-A1c.4093-IVSW	Río Cascabel	1
CT-ÑIV-F3c.3988-IIISW	Río Culebrillas	1
CT-OIII-A1a.4093-IVNW	Río Hualaringo	1
CT-ÑV-B1a.3987-IVNW	Río Mismahuanchi	1
CT-ÑIV-F1c.3988-IVSW	Río Palora	1
CT-ÑIII-F2a.3991-INW	Río del Valle Vicioso	1
CT-ÑIV-D1d.3989-IVNE	Río Verde	1
CT-ÑIII-F2d.3991-ISE	Río Veacu	1
CT-ÑIII-D3b.3992-IIINE	Sincholagua	2
CT-ÑIV-D1c.3989-IVSW	Volcan Tungurahua	1

APPENDIX B

List of available geological sheets

Table 1. List of available geological sheets published by DGGM/INEMIN/CODIGEM, and covering the Cordillera Real of Ecuador, 1:100000 scale

N°	Name	Edition	Year
39	Cariamanga	1	1973
40	Macará	1	1974
55	Saraguro	1	1973
56	Loja	1	1975
57	Gonzanamá	1	1975
58	Las Aradas	1	1979
59	Zumba	1	1979
69	Chimborazo	1	1976
70	Riobamba	1	1978
71	Alausí	1	1975
72	Cañar	1	1975
73	Azogues	Provisional	1980
75	Gualaquiza	Provisional	1989
76	Paquisha	Provisional	1989
85	Píntag	Provisional	1986
86	Chalupas	Provisional	1986
87	San José de Poaló	Provisional	1986
88	Baños	Provisional	1980
90	Macas	Provisional	1989
96	Tulcán	Provisional	1986
97	San Gabriel	Provisional	1986
98	Mariano Acosta	Provisional	1989
99	Reventador	Provisional	1989
100	Baeza	Provisional	1986
101	Tena	Provisional	1986-1987
102	Puerto Napo	Provisional	1986
103	Puyo	Provisional	1980

Table 2. List of available geological sheets published by DGGM/INEMIN/CODIGEM, and covering the Cordillera Real of Ecuador, 1:50000 scale

N°	Name	Edition	Year
73-NW	Azogues	1	1977
74-NW	Sigsig	To be published	

APPENDIX C

List of field maps – Economic Geology

Table 1. Field maps – Cordillera Real Project. Economic Geology

1:50000 scale

Map	Traverse
1	Río Alao - Condorazo
2a	Amaluza - Laguna Cox - Río Isimanchi
2b	Las Aradas
2c	Yangana
2d	Gonzanamá (Cerro Minas)
2e	Santiago
2f	Saraguro
2g	Nabón (Shincata - Betas)
2h	Sigsig - Mina Peggy
2i	Pilzhum
3a	San Miguel de Cuyes - Chigüinda
4a	Principal, Sigsig, Gualaceo, Córdova y Guachapala
4b	Río Paute (Amaluza - Guarumales)
4c	Urdaneta - Río Negro
5a	Ríos Abanico y Upano
5b	Cerro Soroche - Laguna Cubillín - Laguna de Atillo
6a	Río Oyacachi
6b	Río Cosanga
6c	Tena - Río Napo
6d	Río Topo
7a	Río Mataquí - Río Blanco
7b	Río Minas, Quebrada Juan Ibarra y El Playón de San Francisco
7c	Santa Bárbara - La Bonita
7d	La Bonita - La Sofía - Quebrada La Industria
8a	Río Palora
8b	Río Llushin

APPENDIX D

Cordillera Real assay results

Table 1. Volcanogenic massive sulphides

Location Map	Sample	Au ppb	Ag ppm	As ppm	Sb ppm	Bi ppm	Te ppm	Cu ppm	Pb ppm	Zn ppm	Cd ppm	Ba ppm	Cr ppm	Ni ppm	Co ppm	V ppm	Mo ppm	W ppm	Sn ppm	La ppm	Y ppm	K %	Na %	Ca %	Sr ppm	Mg %	Al %	Fe %	Mn ppm
Guarumales (Map 4b)	26-9-91-8	42	1.2	17	<5	<5	<10	490	170	464	1.8	88	14	26	14	16	6	<20	<20	7	7	0.22	0.06	0.32	8	5.38	2.37	5.20	1115
	26-9-91-9	2433	>50	>2000	657	56	<10	13198	>10000	>20000	233.9	1105	2	36	<1	20	44	42	22	1	8	0.03	0.07	4.01	57	5.46	1.15	>10	582
	26-9-91-10	136	4.0	18	<5	12	<10	158	160	213	1.4	37	2	<1	38	2	2	<20	<20	2	1	0.02	0.06	0.03	<1	7.34	3.44	>10	390
	26-9-91-11	174	8.5	156	91	11	<10	500	1984	5462	26.3	318	<1	6	9	5	5	<20	<20	3	16	0.09	0.07	7.94	152	6.75	0.97	>10	1112
	26-9-91-12	108	7.5	230	16	6	<10	739	1386	3231	19.1	240	5	21	19	5	12	<20	22	2	4	0.13	0.07	0.44	9	4.71	1.65	>10	291
	26-9-91-13		>50	532	147	47	<10	1625	>10000	>20000	668.1	103	<1	48	<1	1	37		24	<1	2	0.02	0.06	1.32	30	2.22	0.09	>10	683
	26-9-91-14	8	18.4	106	166	<5	<10	727	3685	8903	35.8	280	3	2	2	2	4	<20	<20	10	8	0.17	0.08	1.08	20	1.23	0.39	2.66	270
	DA-5363	1017	>50	440	552	36	31	3651	>10000	>20000	729.4	70	105	54	5	11	76	444	<20	<1	1	0.03	0.02	0.11	6	3.44	1.09	>10	250
	DA-5364	239	21.8	23	7	10	<10	359	4241	8149	45.2	315	3	3	14	28	10	<20	24	<1	1	0.14	0.02	0.02	3	5.19	2.15	>10	230
	DA-5365	2510	>50	385	1228	15	<10	2265	>10000	>20000	157.2	433	8	55	<1	21	67	<20	27	<1	<1	0.02	0.01	0.03	8	0.33	0.11	>10	109
Minas Pilas (Map 1)	17-6-91-1	479	<0.2	<5	<5	<5	<10	27	24	7	<1	58	66	4		4	10	<20	<20	<1	2	0.12	0.01	<0.01	<1	<0.01	0.22	>10	>100

Table 2. Skarns

Location Map	Sample	Au ppb	Ag ppm	As ppm	Sb ppm	Bi ppm	Te ppm	Cu ppm	Pb ppm	Zn ppm	Cd ppm	Ba ppm	Cr ppm	Ni ppm	Co ppm	V ppm	Mo ppm	W ppm	Sn ppm	La ppm	Y ppm	K %	Na %	Ca %	Sr ppm	Mg %	Al %	Fe %	Mn ppm
Qda. La Industria (Map 7d)	26-5-92-2	7	<0.2	10	<5	<5	<10	131	9	15	<1	23	175	18	9	26	3	<20	<20	15	13	0.12	0.08	1.91	131	0.09	1.04	1.52	10
	28-5-92-1	<5	<0.2	20	<5	7	<10	86	12	120	1	58	95	29	19	61	12	<20	<20	9	11	0.21	0.05	1.65	82	0.34	1.43	3.35	30
	28-5-92-2	<5	<0.2	7	<5	6	<10	90	8	19	<1	43	61	10	16	52	4	<20	<20	8	10	0.22	0.06	1.59	67	0.32	1.35	2.36	20

Table 3. Granodiorite-related mineralization

Location Map	Sample	Au ppb	Ag ppm	As ppm	Sb ppm	Bi ppm	Te ppm	Cu ppm	Pb ppm	Zn ppm	Cd ppm	Ba ppm	Cr ppm	Ni ppm	Co ppm	V ppm	Mo ppm	W ppm	Sn ppm	La ppm	Y ppm	K %	Na %	Ca %	Sr ppm	Mg %	Al %	Fe %	Mn ppm
Yangana-Río Chiriguana (Map 2c)	15-5-91-2	<5	<0.2	<5	<5	<5	<10	2	15	<1	<1	55	117	9	3	5	8	<20	<20	15	2	0.35	0.02	0.02	6	0.02	0.41	1.79	<1
	15-5-91-3	<5	<0.2	<5	<5	<5	<10	8	6	<1	<1	22	99	4	1	3	1	<20	<20	14	3	0.15	0.04	<0.01	3	0.03	0.28	0.46	<1
	15-5-91-4	<5	<0.2	<5	<5	<5	<10	154	<2	3	<1	16	158	5	2	6	107	<20	<20	15	1	0.13	<0.01	<0.01	<1	0.02	0.32	5.15	<1
	15-5-91-5	<5	<0.2	<5	<5	<5	<10	2	<2	64	<1	52	75	14	8	4	15	<20	<20	13	2	0.22	0.02	<0.01	2	0.02	0.38	1.93	<100
	15-5-91-6	<5	<0.2	<5	<5	<5	<10	4	<2	<1	<1	32	55	4	3	1	81	<20	<20	2	<1	0.18	0.02	<0.01	2	0.01	0.32	2.19	<1
Río Ishpingo (Map 4a)	25-9-91-3	319	28.9	31	17	9	<10	2346	56	42	0.09	29	4	13	13	4	90	<20	<20	5	<1	0.21	0.07	0.02	2	0.11	0.31	4.02	45
	25-9-91-5	104	2.6	124	15	10	<10	78	16	6	0.05	26	7	7	13	13	30	<20	<20	<1	<1	0.16	0.06	<0.01	3	0.05	0.32	8.56	66
	25-9-91-6	25	0.6	8	<5	<5	<10	111	75	222	2.6	92	11	17	10	33	2	<20	<20	12	9	0.19	0.13	0.15	11	3.08	2.46	4.59	626
	3334	13	0.9	9	21	<5	<10	278	15	69	0.3	29	57	25	20	90	2	<20	<20	6	16	0.16	0.07	0.07	14	3.66	2.02	6.77	393
	3335	19	2.1	14	11	<5	<10	27	7	1	0.8	56	77	8	3	3	3	<20	<20	2	<1	0.28	0.02	<0.01	3	0.05	0.42	4.48	23
	3336	140	16.4	20	16	<5	<10	1353	17	6	<0.2	34	64	17	27	3	36	<20	<20	4	<1	0.30	0.01	<0.01	2	0.05	0.45	3.77	22
	3337	18	1.5	144	13	<5	<10	65	19	4	<0.2	45	93	7	2	4	10	<20	<20	9	2	0.22	0.02	<0.01	3	0.10	0.42	1.37	64
	3339	36	1.6	58	13	<5	<10	60	15	2	0.6	46	70	5	7	3	1	<20	<20	3	1	0.27	0.02	0.01	4	0.04	0.41	5.22	14
	3340	90	2.9	150	22	<5	<10	83	12	6	0.5	30	104	4	<1	13	30	<20	<20	<1	<1	0.20	0.01	0.01	6	0.05	0.38	7.19	34
	3341	21	3.9	10	10	<5	<10	212	26	2	0.3	30	63	11	12	3	20	<20	<20	6	<1	0.33	0.01	<0.01	3	0.05	0.53	1.96	14
Amaluza-Río Paute (Map 4b)	26-9-91-1	84	5.5	43	11	<5	<10	33	83	174	1.7	154	4	7	2	1	4	<20	<20	<1	2	0.15	0.10	0.01	3	0.56	0.43	3.61	91
	26-9-91-2	68	3.8	21	<5	<5	<10	15	26	92	0.6	83	3	3	1	<1	<1	<20	<20	1	1	0.10	0.13	<0.01	3	0.51	0.47	2.37	86
	26-9-91-4	<5	1.8	10	<5	<5	<10	46	14	158	1.5	69	4	3	1	2	<1	<20	<20	3	2	0.42	0.13	0.02	4	1.81	1.07	2.15	233
	26-9-91-7	20	0.7	9	<5	<5	<10	61	27	561	9.4	63	2	1	2	3	2	<20	<20	6	5	0.49	0.14	0.08	6	1.53	1.01	3.01	546
Salado-Río Upano (Map 5a)	5-11-91-1	11	0.3	<5	9	<5	<10	58	30	70	0.7	199	80	67	11	118	7	<20	<20	4	3	0.37	0.52	3.17	150	2.19	5.12	4.77	421
	5-11-91-2	<5	<0.2	11	8	<5	<10	39	18	18	0.4	34	57	61	6	74	8	<20	<20	2	7	0.05	0.12	2.19	78	0.44	2.62	3.64	355
	5-11-91-3	7	0.3	<5	<5	<5	<10	98	34	41	1.3	60	52	28	13	95	4	<20	<20	7	5	0.08	0.28	3.07	144	1.87	5.82	4.37	392
	5-11-91-4	11	0.2	423	6	<5	<10	63	27	15	0.2	51	70	32	13	119	2	<20	<20	6	8	0.11	0.27	3.03	148	0.67	5.26	3.97	184

Table 4. Porphyry-related mineralization

Location Map	Sample	Au ppb	Ag ppm	As ppm	Sb ppm	Bi ppm	Te ppm	Cu ppm	Pb ppm	Zn ppm	Cd ppm	Ba ppm	Cr ppm	Ni ppm	Co ppm	V ppm	Mo ppm	W ppm	Sn ppm	La ppm	Y ppm	K %	Na %	Ca %	Sr ppm	Mg %	Al %	Fe %	Mn ppm
Isimanchi (Map 2a)	9-5-91-7	171	16.6	10	7	26	11	3626	1318	10457	63.3	40	52	22	29	66	11	<20	<20	3	14	0.42	<0.01	2.47	25	2.01	2.01	4.88	3300
Loma del Loro-Saraguro (Map 2f)	17-5-91-1	<5	<0.2	<5	<5	<5	<10	17	10	71	<1	351	51	5	6	19	1	<20	<20	13	4	0.21	0.05	3.75	144	0.39	0.46	1.69	600
	17-5-91-2	10	<0.2	9	<5	<5	<10	10	2	54	<1	112	26	14	12	62	<1	<20	<20	10	6	0.16	0.03	6.33	47	1.65	2.37	3.43	600
	17-5-91-3	13	0.2	47	<5	<5	<10	32	22	86	<1	45	40	13	13	76	<1	<20	<20	8	7	0.09	0.06	4.02	42	1.17	1.75	4.07	500
	17-5-91-4	13	0.2	16	<5	<5	<10	44	7	40	<1	15	297	10	10	6	3	<20	<20		2	0.04	<0.01	0.04	2	0.26	0.41	2.30	100
	17-5-91-5	12	<0.2	<5	<5	<5	<10	101	7	197	<1	459	68	42	21	112	3	<20	<20	3	13	0.31	0.03	7.92	113	2.37	3.01	4.10	1400
	17-5-91-6	26	0.5	22	12	<5	<10	81	37	157	<1	69	35	29	12	49	3	<20	<20	19	19	0.44	0.02	3.64	92	1.00	1.30	3.34	1400
	17-5-91-7	<5	0.5	42	7	<5	<10	8	10	32	<1	46	28	2	3	3	<1	<20	<20	14	3	0.30	0.01	0.20	12	0.03	0.72	0.42	<1
	17-5-91-8	104	11	104	21	<5	<10	12	29	138	<1	99	37	3	4	3	<1	<20	<20	12	2	0.40	<0.01	0.03	89	0.02	0.75	1.02	100
	17-5-91-9	822	7.2	1143	28	<5	<10	41	91	162	<1	47	35	3	3	4	<1	<20	<20	12	4	0.47	0.01	0.26	18	0.03	0.75	1.89	500
	17-5-91-10	7	<0.2	15	<5	<5	<10	23	6	62	<1	57	36	3	3	21	<1	<20	<20	13	7	0.07	0.10	0.32	51	0.03	0.62	0.75	<1
Cerro Puglla-Saraguro (Map 2f)	17-5-91-11	7	<0.2	<5	<5	<5	<10	26	4	79	<1	52	39	10	19	85	<1	<20	<20	8	9	0.05	0.12	0.49	51	1.64	2.43	3.76	600
	17-5-91-12	73	<0.2	73	5	<5	<10	52	24	3	<1	64	124	11	13	5	15	<20	<20	1	2	0.11	0.03	0.02	18	0.02	0.45	2.50	<1
	17-5-91-13	94	<0.2	33	<5	<5	<10	18	21	3	<1	47	109	17	19	7		<20	<20	1	2	0.12	0.04	0.03	62	0.02	0.51	3.53	<1
	17-5-91-14	22	<0.2	20	<5	<5	<10	18	35	12	<1	45	63	7	7	9	2	<20	<20	<1	<1	0.26	0.12	0.02	107	0.01	1.06	0.57	<1
	23-9-91-1	217	0.4	85	10	<5	<10	75	57	13	1.1	66	9	15	17	5	31	<20	<20	<1	1	0.09	0.07	0.02	41	0.05	0.35	4.54	102
	DA-1357	72	<0.2	47		<5	<10	55	35	67	0.7	142	23	23	20	46	14	<20	<20	8	17	0.16	0.09	0.23	65	1.47	1.63	3.20	200
	DA-1370	<5	<0.2	19		23	12	18	360	18	<0.2	408	4	5	4	6	4	<20	<20	<1	<1	0.04	0.07	0.02	17	0.02	0.05	2.32	40
Peggy Mine-Sigsig (Map 2h)	25-5-91-2	2360	30.7	>2000	144	>2000	11	4763	289	526	<0.2	12	96	43	140	<1	2	<20	88	<1	2	0.04	0.05	0.06	6	0.02	0.09	>10	34
	25-5-91-5	16	26.4	>2000	17	54	<10	498	48	46	<0.2	42	87	10	9	<1	118	<20	42	1	2	0.07	0.05	0.01	20	0.03	0.13	5.99	27
	25-5-91-6	38	32.1	>2000	31	719	<10	9126	30	220	<0.2	34	129	16	37	<1	2	21	110	6	4	0.07	0.04	0.21	89	0.09	0.19	>10	274
	26-5-91-1	42	>50	1848	82	401	40	>20000	299	4473	24	12	121	16	16	<1	<1	489	574	<1	1	0.13	0.26	0.09	14	0.17	0.11	>10	1773
	26-5-91-2	175	>50	>2000	29	219	<10	>20000	57	892	<0.2	34	100	20	51	<1	2	22	526	4	5	0.08	0.04	0.33	50	0.07	0.20	9.20	532
	26-5-91-3	84	11.1	>2000	17	176	<10	4191	17	164	<0.2	89	162	16	25	<1	3	<20	45	7	5	0.03	0.04	0.13	117	0.02	0.14	5.57	149
	26-5-91-4	<5	2.7	194	17	110	<10	921	42	115	0.9	49	100	18	7	2	3	<20	37	1	5	0.04	0.05	0.20	17	0.08	0.18	7.5	390
	26-5-91-6	<5	4.5	249	<5	<5	<10	169	211	742	3.2	142	40	17	13	26	<1	<20	36	3	2	0.37	0.05	0.13	23	0.31	0.71	5	542
	26-5-91-7	28	29.9	>2000	33	12	<10	245	2063	1560	<0.2	91	90	26	6	2	13	<20	129	1	<1	0.21	0.04	<0.01	10	0.04	0.32	4.52	110
	26-5-91-8	<5	4.5	374	6	<5	<10	77	499	3025	17.8	79	30	1	<1	<1	<1	<20	35	1	3	0.36	0.05	0.02	3	0.15	0.54	4.35	460
	26-5-91-9	2660	>50	>2000	207	110	<10	221	>10000	1523	11.8	5	36	61	27	<1	3	395	145	<1	2	0.06	<0.01	<0.01	4	<0.01	0.13	>10	100
	26-5-91-10	2313	>50	>2000	59	1251	<10	1066	417	66	46.9	5	70	20	75	<1	<1	1242	96	2	2	0.05	<0.01	<0.01	16	<0.01	0.09	>10	200
	26-5-91-10A	219	>50	>2000	55	19	<10	1457	5195	>20000	916.5	50	45	<1	11	21	<1	<20	1242	<1	3	0.41	0.24	0.48	6	0.51	0.71	6.17	1119
	26-5-91-11		2.1	>2000	30	<5	<10	1200	<2	1558	<0.2	7	10	<1	<1	<1	5	<20	94	<1	2	0.05	0.03	0.01	<1	0.01	1.3	>10	95
	27-5-91-1	109	5.4	>2000	20	61	<10	67	48	119	<0.2	22	156	12	4	1	4	<20	79	<1	<1	0.07	0.04	0.01	7	0.02	0.1	1.41	89
	27-5-91-2	25	4.7	692	7	22	<10	55	38	25	<0.2	31	63	2	<1	2	31	<20	49	6	1	0.33	0.04	<0.01	14	0.05	0.42	1.42	20
	27-5-91-5	<5	3.6	55	<5	7	<10	10	44	176	1.5	66	67	4	1	4	<1	24	<20	19	2	0.30	0.04	<0.01	3	0.06	0.60	0.46	70
	27-5-91-6	<5	4.3	388	<5	11	<10	41	309	188	<0.2	110	27	1	1	1	3	<20	<20	5	3	0.48	0.05	<0.01	5	0.03	0.60	0.02	20
	27-5-91-7	21	16.7	76	11	7	<10	46	1210	715	14.1	99	60	24	17	9	3	<20	71	4	1	0.37	0.05	0.14	17	0.19	0.73	2.67	243
	26-6-91-3	23	50	557	<5	6	<10	69	10	76	<0.2	178	62	2	<1	<1	4	<20	23	7	2	0.32	0.05	<0.01	4	0.07	0.73	0.81	24
	DA-1352	16	8.3	1073	14	18	11	120	24	12	<0.2	118	4	2	<1	<1	3	<20	77	5	3	0.34	0.06	0.01	7	0.09	0.60	2.11	41
	DA-1353	395	8.5	>2000	72	5	<10	39	89	189	0.4	77	23	8	11	7	2	<20	<20	14	4	0.78	0.07	0.28	8	0.12	1.09	2.95	393
	DA-1354	19	1.5	141	16	<5	10	10	34	77	0.3	65	13	2	4	5	1	<20	<20	14	3	0.87	0.07	0.24	14	0.15	1.34	0.73	130
	DA-1355	7	<0.2	<5	7	<5	<10	26	8	83	0.4	164	21	15	15	110	2	<20	<20	16	12	0.11	0.21	2.92	47	3.72	2.36	3.06	935
	DA-1356	<5	1.2	316	9	<5	<10	9	80	32	<0.2	61	94	34	2	10	14	<20	<20	11	3	0.39	0.09	0.13	37	0.26	1.22	1.82	94
	DA-1360	27	48.1	1278	26	53	<10	572	1966	703	4.4	159	10	15	6	15	2	<20	91	5	2	0.49	0.08	0.02	127	0.10	1.26	3.49	35
	DA-1361	99	26	>2000	29	12	<10	172	4204	7648	37.4	197	9	4	4	12	1	<20	171	5	2	0.31	0.11	0.01	18	0.05	0.75	1.28	50
	DA-1362	21	16.5	340	9	11	<10	78	140	9328	68.7	56	4	3	1	5	2	36	102	12	3	0.40	0.06	<0.01	14	0.06	0.59	1.93	63
	DA-1363	11	2.1	115	14	21	10	77	54	280	2.3	38	62	3	2	5	35	<20	24	10	2	0.61	0.06	0.01	25	0.14	1.15	1.58	76
	DA-1364	28	6.3	104	14	38	<10	67	60	71	0.2	56	8	<1	<1	7	60	89	129	17	2	0.55	0.06	<0.01	17	0.15	0.93	2.09	48
	DA-1365	1329	9.8	649	32	<5	<10	29	70	85	<0.2	64	3	3	7	6	5	<20	<20	12	3	0.58	0.07	0.21	57	0.07	0.83	2.32	115
	DA-1366	38	2.6	274	13	<5	<10	23	34	106	0.4	63	18	4	6	6	2	<20	<20	13	3	0.71	0.08	0.29	19	0.12	0.96	1.19	1009
	DA-1367	41	1.1	<5	7	<5	<10	75	55	236	1.4	167	39	43	15	68	9	<20	<20	25	13	0.50	0.10	3.67	112	3.44	2.46	4.23	1363
	DA-1368	<5	0.4	10	<5	9	<10	31	9	317	2.1	437	4	5	5	21	3	<20	<20	16	6	0.35	0.15	3.04	120	1.56	0.63	2.03	648
	DA-1369	49	2.2	85	7	<5	<10	149	141	92	0.3	99	20	9	2	35	54	<20	<20	29	7	0.35	0.09	0.20	24	1.70	1.28	2.49	339
	DA-1372	<5	1.4	51	5	5	<10	10	138	27	0.5	295	2	3	2	<1	4	<20	<20	1	2	0.32	0.97	<0.01	5	0.08	1.16	2.59	91
	DA-1373	137	>50	>2000	177	232	<10	16477	>10000	9025	52.9	54	10	42	64	13	9	89	1514	<1	2	0.19	0.07	0.01	62	0.04	0.65	6.76	62
	DA-1374	114	>50	>2000	57	66	<10	1064	198	>20000	2268.9	29	5	3	11	3	7	241	1126	<1	1	0.21	0.19	0.02	132	0.06	0.42	9.32	360
	DA-1375	637	>50	1495	244	>2000	10	>20000	405	778	5.8	42	4	10	20	<1	12	88	390	3	2	0.04	0.68	0.05	38	0.14	0.19	>10	974
	DA-1376	399	26.7	1005	111	161	<10	2100	74	3005	8.1	21	17	5	<1	<1	6	<20	467	<1	6	0.14	0.05	0.03	19	0.06	0.82	>10	277
Ayllón (Map 4a)	19-9-91-1	12690	19.1	>2000	102	5	<10	58	325	130	1.6	39	8	12	6	2	<1	<20	<20	<1	1	0.12	0.06	0.02	16	0.08	0.17	5.39	185
	19-9-91-3	6258	5.4	>2000	28	8	<10	51	1253	890	4.5	51	8	65	44	<1	1	<20	<20	<1	<1	0.08	0.06	0.03	3	0.07	0.12	6.77	119
	19-9-91-9	165	0.8	>2000	5	<5	<10	67	7	27	<0.2	8	6	25	51	1	<1	<20	<20	10	7	0.09	0.06	0.08	3	1.05	0.15	6.22	1450
	21-9-91-1	101540	>50	>2000	>2000	29	<10	2113	6795	3143	7.9	25	7	10	3	<1	<1	<20	<20	<1	<1	0.07	0.06	0.05	4	0.16	0.10	4.53	123

Table 5. Volcanic-hosted epithermal mineralization

Location Map	Sample	Au ppb	Ag ppm	As ppm	Sb ppm	Bi ppm	Te ppm	Cu ppm	Pb ppm	Zn ppm	Cd ppm	Ba ppm	Cr ppm	Ni ppm	Co ppm	V ppm	Mo ppm	W ppm	Sn ppm	La ppm	Y ppm	K %	Na %	Ca %	Sr ppm	Mg %	Al %	Fe %	Mn ppm
Tierras Coloradas (Map Río Calvas)	7-5-91-1	<5	<0.2	17	<5	<5	<10	20	10	<1	<1	8	133	4	<1	19	2	<20	<20	<1	<1	<0.01	<0.01	<0.01	1	<0.01	0.19	3.52	<1
	7-5-91-2	6	<0.2	10	<5	<5	<10	125	32	2	<1	13	43	2	3	136	<1	<20	<20	<1	4	0.05	<0.01	<0.01	2	0.03	1.69	<10	<1
	7-5-91-3	6	<0.2	25	<5	<5	<10	59	4	<1	<1	5	19	1	<1	64	<1	<20	<20	<1	1	0.03	<0.01	0.04	5	0.02	1.43	6.17	<1
	7-5-91-4	<5	<0.2	8	<5	<5	<10	18	<2	5	<1	40	130	4	<1	42	5	<20	<20	1	<1	0.01	<0.01	0.05	16	0.12	0.67	3.72	100
	7-5-91-7	<5	<0.2	<5	<5	<5	<10	15	2	3	<1	47	149	7	3	14	3	<20	<20	<1	1	0.03	0.15	0.29	161	0.08	0.48	0.76	100
Cariamanga	7-5-91-CM	<5	<0.2	95	<5	<5	<10	22	5	<1	<1	27	10	11	10	16	<1	<20	<20	<1	<1	0.01	<0.01	<0.01	40	<0.01	1.44	4.34	<1
Gima-Cerro Colorado (Map 3a)	DA-5355	149	3	51	6	8	<10	287	67	16	1	122	21	13	10	4	2	<20	<20	<1	<1	<0.01	0.01	0.02	4	0.01	0.26	5.78	71
	DA-5356	228	3.7	150	14	7	<10	286	45	11	0.8	233	11	4	6	1	<1	<20	<20	<1	<1	<0.01	0.01	<0.01	3	<0.01	0.08	4.46	44
	DA-5357	143	0.6	61	5	7	<10	99	25	15	0.4	20	4	<1	<1	5	2	<20	<20	<1	<1	0.01	0.01	<0.01	2	<0.01	0.12	3.63	12
	DA-5358	121	0.8	170	13	6	<10	111	88	45	0.3	758	4	1	<1	5	2	<20	<20	<1	<1	0.01	0.01	<0.01	2	<0.01	0.07	4.21	19
	DA-5359	540	4.3	207	135	47	<10	52	26	8	0.3	13	35	11	<1	1	7	<20	72	<1	<1	0.02	0.01	<0.01	3	<0.01	0.10	2.32	27
	DA-5360	107	3.3	30	15	6	<10	12	179	54	0.6	253	180	65	1	<1	29	<20	<20	<1	<1	0.01	0.01	<0.01	4	<0.01	0.05	1.19	56
	DA-5361	451	0.8	17	<5	<5	<10	8	17	13	0.9	15	39	11	<1	2	5	<20	<20	<1	<1	0.01	0.01	<0.01	1	<0.01	0.10	1.73	37
	DA-5362	4259	1.4	240	13	9	10	57	40	101	0.8	34	44	17	2	5	7	<20	30	<1	<1	0.01	0.01	0.17	3	<0.01	0.06	8.51	250
	DA-5366	716	6.8	334	257	22	24	77	358	57	<0.2	37	17	<1	<1	56	30	<20	<20	<1	<1	0.04	0.03	<0.01	40	0.01	1.24	>10	43
Cuchil-Satunsaray (Map 4a)	22-9-91-1	80	1.6	45	5	<5	<10	45	157	15	1	285	5	6	9	16	7	<20	<20	<1	<1	0.04	0.06	0.01	19	0.02	0.06	3.32	44
	22-9-91-3	4013	1.3	70	11	<5	<10	10	302	85	<0.02	427	12	3	<1	104	<1	<20	<20	<1	<1	0.09	0.07	0.02	249	0.06	0.43	3.06	65
	22-9-91-4	11	0.2	20	<5	5	<10	16	219	5	0.8	265	7	8	11	11	3	<20	<20	<1	<1	0.06	0.06	0.02	42	0.01	0.06	2.83	41
	22-9-91-5	307	1.7	69	15	<5	<10	11	126	29	0.3	51	5	3	<1	64	<1	<20	<20	<1	<1	0.04	0.06	0.01	24	0.02	0.13	1.19	44
	22-9-91-6	28	0.3	15	<5	<5	<10	4	79	5	0.5	181	4	2	<1	6	2	<20	<20	<1	<1	0.02	0.06	<0.01	11	<0.01	0.02	0.63	28
	22-9-91-7	71	0.3	26	8	<5	<10	6	62	24	0.3	26	6	4	<1	39	<1	<20	<20	<1	<1	0.02	0.06	<0.01	14	0.01	0.04	1.12	52
	22-9-91-8/9	25	0.2	6	6	7	13	3	70	7	<0.2	841	5	2	<1	5	<1	<20	<20	<1	<1	0.02	0.06	0.01	18	0.01	0.06	0.85	24
	22-9-91-10/11	38	0.6	23	6	16	<10	8	708	15	0.5	511	4	4	2	5	2	<20	<20	<1	<1	0.03	0.06	<0.01	8	<0.01	0.03	1.41	28
	DA-1358	<5	<0.2	16	8	7	15	19	240	7	0.04	236	8	9	17	13	2	<20	<20	<1	<1	0.06	0.07	0.03	43	0.06	0.12	3.24	48
	DA-1359	<5	<0.3	24	11	60	17	14	472	11	0.04	105	6	8	6	13	6	<20	<20	<1	<1	0.03	0.07	0.01	12	0.02	0.07	3.56	67
	DA-1371	<5	<0.2	19	6	23	12	18	360	18	<0.02	408	4	5	1	6	6	<20	<20	<1	<1	0.04	0.07	0.02	17	0.02	0.05	2.32	48
Loma Quipal-Sigsig (Map 4a)	3338	85	19	98	19	<5	<10	306	52	23	1.5	1002	75	4	<1	24	2	<20	<20	<1	<1	0.10	0.06	<0.01	46	<0.01	0.59	7.47	147
	3342	112	1	89	11	<5	<10	168	105	16	<0.2	36	49	2	<1	19	3	<20	<20	1	<1	0.14	0.07	0.02	56	<0.01	0.72	3.15	21
	3343	12	1.7	70	33	<5	<10	66	148	23	0.8	249	46	1	1	20	2	<20	<20	<1	<1	0.14	0.07	0.01	57	0.01	0.41	7.03	27
	5257	12	<0.2	98		<5		127	33	<1	<1			<1	<1		3												
	5258	241	4.5	16		13		1157	142	419	<1			9	11		2												
	5261	70	6.7	51		<5		2706	132	11	<1			8	9		2												
Principal-Río Shío (Map 4a)	27-9-91-3	44	0.9	20	5	6	<10	424	59	16	0.3	52	4	9	119	10	3	<20	<20	<1	<1	0.10	0.07	0.02	24	0.03	0.30	5.56	56
Río Collay (Map 4a)	20-11-91-2	<5	13.1	16	10	<5	<10	45	67	5	0.3	450	25	7	2	6	2	<20	<20	<1	1	0.04	0.02	0.11	8	0.03	0.16	3.33	143
Osogochi (Map 5a and 5b)	6-11-91-3	32	1.4	7	12	8	<10	2730	25	5	0.9	12	25	4	91	17	56	<20	<20	<1	<1	0.12	0.02	<0.01	<1	0.59	0.37	3.88	67
	6-11-91-4	9	0.4	57	13	9	<10	21	33	6	0.9	26	11	14	71	6	7	<20	<20	<1	1	0.25	0.02	0.01	2	0.08	0.38	8.49	38
	6-11-91-4b	12	0.6	67	14	8	<10	18	37	4	0.8	24	11	17	81	5	6	<20	<20	<1	<1	0.23	0.02	<0.01	2	0.04	0.34	9.44	29
	13-11-91-1	<5	<0.2	34	11	<5	<10	49	48	58	1.1	88	18	19	7	18	9	<20	<20	5	3	0.34	0.08	0.06	9	1.99	1.14	3.95	219
	13-11-91-2	12	1.8	37	12	<5	<10	30	116	39	0.7	81	14	91	17	9	3	<20	<20	8	2	0.31	0.04	0.03	3	0.45	0.59	3.82	87
	13-11-91-4	38	0.3	<5	9	6	<10	68	58	197	1.3	41	16	11	16	118	5	<20	<20	3	6	0.25	0.36	1.67	134	4.20	3.55	5.10	1328
	13-11-91-5	64	0.3	12	9	<5	<10	305	78	108	1.4	110	30	19	3	92	<1	<20	<20	11	4	0.63	0.22	0.86	42	3.51	2.09	2.76	2244
	13-11-91-7	59	0.2	<5	11	<5	<10	105	23	9	<0.2	117	13	4	20	9	42	<20	<20	3	6	0.37	0.06	0.05	24	0.56	0.77	4.70	82
	13-11-91-8	12	0.4	<5	10	<5	<10	53	26	36	1	74	40	26	29	49	2	<20	<20	4	6	0.41	0.09	0.41	24	3.19	1.51	5.32	212
Atillo (Map 5b)	16-11-91-2	<5	<0.2	<5	10	<5	<10	34	24	78	<0.2	60	50	30	15	79	3	<20	<20	15	12	0.19	0.09	0.56	25	2.24	2.12	4.20	607
	16-11-91-3	9	0.3	<5	9	<5	<10	32	37	67	<0.2	70	30	27	14	42	4	<20	<20	16	10	0.15	0.04	2.20	24	2.79	1.99	4.03	526
	16-11-91-4	<5	<0.2	<5	10	<5	<10	33	39	53	1	131	15	26	17	35	2	<20	<20	12	7	0.23	0.03	1.66	27	2.73	2.07	4.44	647
Cubillín	3196	<0.005	<0.2	554	28	<5	<10	30	27	23	<1	20	42	24	9	27	3	<20	<20	15	5	0.29	0.03	0.01	12	0.41	1.49	3.02	115
	3197	<0.005	<0.2	318	6	<5	<10	46	10	86	<1	91	50	16	7	68	1	<20	<20	19	8	0.17	0.13	0.12	28	0.84	1.79	2.46	308
	3198	0.018	0.3	230	69	<5	<10	86	179	102	<1	819	16	12	16	30	2	<20	<20	10	2	0.26	0.02	<0.01	33	0.52	2.43	4.26	1473
	3199	<0.005	<0.2	1456	13	<5	<10	73	11	6	<1	291	20	4	1	24	2	<20	<20	6	<1	0.28	0.03	0.02	26	0.13	1.37	4.82	33

Table 6. Mesothermal veins

Location Map	Sample	Au ppb	Ag Ppm	As Ppm	Sb Ppm	Bi Ppm	Te Ppm	Cu Ppm	Pb Ppm	Zn Ppm	Cd Ppm	Ba Ppm	Cr Ppm	Ni Ppm	Co Ppm	V Ppm	Mo ppm	W ppm	Sn ppm	La ppm	Y ppm	K %	Na %	Ca %	Sr ppm	Mg %	Al %	Fe %	Mn ppm
Las Aradas (Map 2b)	11-05-91-1		<0.2	<5	<5	<5	<10	6	<2	9	<1	11		5	5	1	3	<20	<20	<1	<1	<0.01	<0.01	<0.01	1	<0.01	0.05	1.73	800
Principal-Río Shio (Map 4a)	27-9-91-5	24	0.3	<5	<5	<5	<10	66	6	26	0.9	10	2	4	7	74	2	<20	<20	<1	5	0.03	0.09	5.15	76	1.42	1.40	2.36	1139
Atillo-Laguna Negra (Map 5b)	15-11-91-3	13	0.9	<5	17	15	<10	119	108	299	1.8	116	30	27	36	77	16	<20	<20	<1	5	0.38	0.03	1.00	13	4.95	2.21	>10	1816
	15-11-91-4	8	0.5	<5	6	<5	<10	345	19	106	<0.2	224	13	3	6	12	3	<20	<20	3	12	0.68	0.06	0.41	6	1.83	1.09	3.35	987
	15-11-91-5	7	<0.2	<5	12	<5	<10	28	30	119	<0.2	73	21	13	10	57	5	<20	<20	<1	3	0.11	0.03	3.62	70	3.82	1.52	3.43	1906
	15-11-91-6	18	0.4	<5	12	<5	<10	49	26	77	1.6	173	48	24	15	63	6	<20	<20	9	15	0.31	0.07	4.02	39	4.49	2.04	4.41	1531
Río Mataquí-Río Blanco (Map 7a)	20-5-92-5	24	5.0	6	<5	11	<10	18	755	74	<1.0	23	532	31	3	19	11	<20	<20	1	2	0.05	<0.01	0.98	32	0.45	0.15	1.06	20
	20-5-92-6	11	<0.2	25	<5	10	<10	97	49	163	<1.0	118	60	84	23	30	2	<20	<20	1	7	0.27	0.06	>10	202	3.52	0.51	4.40	90
	20-5-92-8	17	<0.2	<5	<5	7	<10	4	393	113	<1.0	33	181	15	7	5	9	<20	<20	6	4	0.03	0.07	6.98	330	0.65	0.13	2.89	80
Monte Olivo (Map 7a)	21-5-92-6	9	<0.2	<5	<5	<5	<10	121	6	2	<1.0	4	564	43	14	2	5	<20	<20	1	<1	0.01	<0.01	<0.01	<1	<0.01	0.03	1.30	10
Río Chingual (Map 7c and 7d)	30-5-92-1	<5	<0.2	13	<5	<5	<10	135	3	4	<1.0	13	553	22	6	3	5	<20	<20	<1	1	0.04	<0.01	<0.01	<1	0.01	0.07	1.55	10
	31-5-92-2	<5	<0.2	<5	<5	<5	<10	9	2	18	<1.0	94	95	5	19	6	5	<20	<20	7	11	0.33	0.02	0.15	10	0.16	0.92	1.91	120
	31-5-92-3	<5	0.4	<5	<5	<5	<10	708	3	9	<1.0	17	340	92	72	5	3	<20	<20	<1	<1	0.04	0.01	0.06	3	0.05	0.11	3.40	10

Table 7. Mineralized schist/shear zones

Location Map	Sample	Au ppb	Ag ppm	As ppm	Sb ppm	Bi ppm	Te ppm	Cu ppm	Pb ppm	Zn ppm	Cd ppm	Ba ppm	Cr ppm	Ni ppm	Co ppm	V ppm	Mo ppm	W ppm	Sn ppm	La ppm	Y ppm	K %	Na %	Ca %	Sr ppm	Mg %	Al %	Fe %	Mn ppm
Yangana San Antonio Road (Map 2c)	15-05-91-8	<5	<0.2	<5	<5	<5	<10	26	11	74	<1.0	114	139	20	8	30	5	<20	<20	13	4	0.70	0.05	0.08	6	0.59	1.41	2.36	300
	15-05-91-9	<5	<0.2	9	<5	<5	<10	26	15	34	<1.0	55	117	8	3	23	63	<20	<20	26	5	0.35	0.03	0.02	5	0.65	1.67	2.77	200
	15-05-91-10	<5	<0.2	<5	<5	<5	<10	68	4	65	<1.0	103	109	21	9	33	3	<20	<20	19	4	0.81	0.03	0.03	3	0.81	1.88	3.20	200
	15-05-91-11	<5	<0.2	<5	<5	<5	<10	30	9	74	<1.0	84	112	33	20	39	2	<20	<20	23	5	0.60	0.04	0.07	4	1.03	2.07	3.21	400
Chigüinda (Map 3a)	31-7-91-2	24	<0.2	14	<5	<5	<10	224	<2	25	<1.0	97	79	32	16	20	2	<20	<20	17	13	0.62	0.03	0.07	6	0.40	1.80	3.25	200
	31-7-91-3	9	<0.2	<5	<5	<5	<10	17	<2	5	<1.0	46	177	6	3	4	5	<20	<20	5	3	0.18	0.02	0.14	3	0.03	0.32	0.73	100
	31-7-91-4	10	0.5	20	41	<5	<10	100	<20	9	<1.0	59	172	8	3	3	390	<20	<20	9	1	0.17	<0.01	<0.01	<1	0.02	0.27	2.02	<1
	7-8-91-1	12	<0.2	12	<5	49	<10	28	<20	216	<1.0	120	66	12	16	63	1	<20	<20	8	5	0.68	0.24	2.27	102	1.57	2.96	3.39	700
	7-8-91-2	<5	<0.2	<5	<5	<5	<10	8	<2	5	<1.0	7	212	5	2	5	8	<20	<20	2		0.06	0.01	0.02	1	0.05	0.20	0.97	<1
	7-8-91-3	10	<0.2	<5	<5	<5	<10	9	14	13	<1.0	15	64	5	2	5	2	<20	<20	29	6	0.41	0.02	<0.01	3	0.07	0.82	1.59	<1
	7-8-91-4	10	<0.2	7	9	<5	<10	19	3	5	<1.0	16	178	5	3	5	8	<20	<20	19	3	0.26	0.01	<0.01	<1	0.02	0.42	1.30	<1
	7-8-91-5	10	<0.2	<5	<5	<5	<10	13	2	26	<1.0	142	83	20	8	24	37	<20	<20	20	11	0.58	0.03	0.11	4	0.24	1.21	1.82	300
	7-8-91-6	15	<0.2	<5	<5	<5	<10	72	<2	6	<1.0	79	126	10	9	8	41	<20	<20	18	7	0.41	0.02	0.02	2	0.09	0.78	1.43	100
	7-8-91-7	1082	1.0	<5	<5	<5	<10	61	2030	38	<1.0	152	88	25	14	34	5	<20	<20	20	9	0.59	0.04	0.17	4	0.41	1.58	3.19	800
	7-8-91-8	<5	0.3	<5	<5	<5	<10	33	<2	12	<1.0	45	159	7	6	5	9	<20	<20	14	3	0.24	0.01	<0.01	3	0.03	0.42	2.20	100
	7-8-91-9	6	<0.2	<5	<5	<5	<10	66	2	34	<1.0	65	73	24	10	32	2	<20	<20	19	3	0.31	0.03	0.02	6	0.86	2.04	3.90	300
	7-8-91-10	10	<0.2	<5	<5	<5	<10	16	<2	<1	<1.0	24	134	15	9	3	5	<20	<20	10	2	0.25	<0.01	<0.01	<1	0.03	0.38	2.74	<1
	7-8-91-11	8	0.3	<5	<5	<5	<10	18	<2	<1	<1.0	57	115	6	3	3	11	<20	<20	15	2	0.24	<0.01	<0.01	1	0.03	0.39	1.57	<1
	7-8-91-12	10	0.5	<5	26	<5	<10	70	<2	6	<1.0	29	114	8	16	3	3	<20	<20	5	1	0.22	0.01	<0.01	<1	0.04	0.38	4.09	<1
	7-8-91-13	15	<0.02	<5	<5	<5	<10	30	<2	16	<1.0	41	116	15	14	4	4784	<20	<20	9	2	0.27	0.01	<0.01	2	0.04	0.32	2.92	<1
Río Santa Bárbara (Map 4a)	20-9-91-1	817	0.9	225	<5	<5	<10	186	15	11	1.1	17	8	10	7	3	<1	<20	<20	4	4	0.10	0.08	0.13	7	0.41	0.30	1.58	109
	20-9-91-2	29	0.4	101	<5	<5	<10	22	29	47	0.4	77	13	29	13	9	<1	<20	<20	5	5	0.19	0.07	0.25	12	1.06	0.96	2.90	160
Río Collay (Map 4a)	20-11-91-3	7	0.3	<5	11	10	<10	118	26	138	2.4	16	28	6	18	45	2	<20	<20	13	22	0.10	0.04	0.14	2	4.31	2.55	7.16	<10
Río Cofanes (Map 7d)	29-5-92-1	<5	0.5	<5	<5	6	<10	342	5	113	<1.0	29	219	106	26	87	36	<20	<20	11	4	0.92	0.06	0.01	4	1.17	1.58	3.98	30

Table 8. Miscellaneous mineralization

Location Map	Sample	Au ppb	Ag ppm	As ppm	Sb ppm	Bi ppm	Te ppm	Cu ppm	Pb ppm	Zn ppm	Cd ppm	Ba ppm	Cr ppm	Ni ppm	Co ppm	V ppm	Mo ppm	W ppm	Sn ppm	La ppm	Y ppm	K %	Na %	Ca %	Sr ppm	Mg %	Al %	Fe %	Mn ppm
Monte Olivo MoS_2 vein (Map 7a)	19-5-92-2	<5	<0.2	32	<5	<5	<10	20	12	11	<1.0	283	476	24	4	6	964	<20	<20	<1	2	0.05	0.04	0.74	10	0.29	0.19	1.20	20
Qda. Agua Clara (Map 7c)	25-5-92-1	12	<0.2	<5	<5	7	<10	111	<2	63	<1.0	100	117	14	19	82	3	<20	<20	1	5	1.36	0.09	0.56	37	2.20	2.60	3.03	60
	25-5-92-2	<5	<0.2	<5	<5	37	<10	272	3	47	<1.0	103	137	25	33	16	4	59	<20	4	8	0.61	0.10	1.10	37	0.95	1.97	3.77	40
Monte Olivo (Map 7a)	21-5-92-7	450	11.8	255	<5	22	<10	44	105	24	<1.0	20	107	7	2	29	13	<20	<20	1	2	0.77	0.94	0.23	126	0.11	0.24	0.21	<10
	4173	64	3.1	132	<5	<10	89	225	52	<0.2	85	36	4	1	20	30	<20	<20	24	6	0.35	0.08	0.09	0.22	56	0.87	1.88	<5	178
	4174	6	1.1	53	<5	<10	9	26	17	0.4	102	34	1	1	7	3	<20	<20	21	7	0.29	0.06	0.07	0.04	20	0.70	0.64	<5	22
	4175	15	20.1	362	9	<10	117	116	97	<0.2	772	10	6	198	8	<1	<20	<20	16	8	0.36	0.06	0.02	0.02	17	2.48	3.11	<5	<20000
	4179	1593	7.1	>2000	<5	<10	37	299	262	<0.2	45	40	5	5	16	1	<20	<20	13	4	0.28	0.09	0.86	0.19	40	0.82	2.35	<5	1183
	4187	<5	<0.2	<5	<5	<10	27	14	85	0.9	151	9	3	5	24	2	<20	<20	13	5	0.03	0.09	0.40	0.06	108	1.31	3.28	<5	384
	4188	<5	0.8	52	<5	<10	8	31	35	0.3	49	18	<1	2	6	1	<20	<20	10	2	0.25	0.07	0.08	0.04	15	0.76	0.83	<5	80
	4189	<5	<0.2	<5	19	27	50	43	71	<0.2	20	112	54	19	79	5	<20	<20	8	6	0.14	0.07	4.87	3.72	58	2.73	3.36	10	803
	4193	750	8.7	1819	<5	<10	32	403	532	1.0	30	26	6	6	8	<1	<20	<20	16	5	0.26	0.06	8.25	0.08	20	0.55	2.26	<5	2550
	4194	2744	16.3	>2000	<5	<10	60	638	667	1.8	33	39	5	4	6	4	<20	<20	13	4	0.28	0.05	1.54	0.14	31	0.44	2.52	<5	2870
Monte Olivo Pegmatite (Map 7a)	19-5-92-3	69	<0.2	<5	<5	5	<10	6	5	2	<1.0	46	123	3	<1	2	<20	<20	2	5	0.35	0.11	0.65	0.50	23	0.19	15.15	0.86	40

APPENDIX E

Note regarding XRF analyses referred to in Litherland et al. (1990)

Note regarding X-ray Fluorescence (XRF) analyses referred to in Litherland et al. (1990) and reported here.

The XRF analytical results (mostly on stream sediment samples), referred to in Litherland et al. (1990), and reported here are given as “weak”, “moderate”. and “high” values. based upon XRF peak highs. These analyses have not been calibrated against spiked or international rock standards with known element values and, therefore, the results may not be accurate and should be treated with caution.

APPENDICES F1-F8

Commission reports from the Cordillera Real –
Economic Geology Survey

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No. 3674

QUITO, MARCH, 1991

TO : GERENTE TÉCNICO

FROM : DR. RICHARD JEMIELITA

SUBJECT : Commission report for the provinces of Azuay (San Bartolome, Pilzhum, Sigsig mines) and Chimborazo (Alao, Peltetec, Condorazo) from February 18 to March 08.

1. INTRODUCTION

1.1 Project context

The Cordillera Real Geological Project, a technical collaboration between the governments of Ecuador and Great Britain, includes in its third phase the Economic Potential of the Cordillera Real subproject. By virtue of this, the first visit was made to the outcrops previously studied by the Project, with the purpose of becoming familiar with said lithologies and their respective interpretation.

1.2. Objective

Reconnaissance and start of the field program for the Economic Potential of the Cordillera Real subproject.

During the first days, work was carried out with the Head of Mission on the visit to the previously studied mines, and a geological study of the outcrops and boulders was performed, as well as the taking of rock samples, heavy sediments, and stream sediments for their respective chemical, petrographic, and palynomorph study.

1.3 Assigned personnel

To carry out this work, the commission was composed of:

Dr. Richard Jemielita (ODA/BGS)

Sr. Gonzalo Aguilar (INEMIN)

Sr. Manuel Célleri (INEMIN)

1.4 Transport

Jeep Land Rover, license plate AT-0274, from the British Mission.

1.5 Detailed activities

Month	Day	Traverse
February	18	Quito-Ambato-Baños-Penipe-Riobamba
	19	Río Alao-Río Huarguallá
	20	Riobamba-Guamote-Chunchi-Cuenca
	21	Cuenca-San Bartolomé-Cuenca
	22	Cuenca-Gualaceo-Chordeleg-Sigsig-Cuenca
	23	Cuenca-Azogues-Pilzhum-Cuenca
	24	Cuenca-Riobamba
	25	Riobamba-Río Quishpe-Río Basancel
	26	Río Basancel
	27	Río Basancel
	28	Río Basancel-Río Quishpe-Riobamba
March	01	Mina Curiayana-Mina Cacadrón
	02	Mina Cruzacta
	03	Mina Agua Santa
	04	Río Alao-Placabamba
	05	Placabamba-Condorazo
	06	Condorazo-Laguna Verde
	07	Laguna Verde-Mina de Pilas-Placabamba
	08	Placabamba-Alao-Quito.

1.6 Access

Many areas are accessible by four-wheel drive vehicle (Land Rover). The Río Quishpe, Río Alao upstream from the town of Alao, and Condorazo areas were only accessible on horseback and/or on foot.

1.7 Previous work

The Baños, Penipe and Río Alao areas have been surveyed geologically by Litherland et al. (1990). Pilzhum and Tampanchi have been studied by several companies and individuals (INEMIN-Misión Belga, 1988; Litherland et al., 1990). The Río Paute area was surveyed geologically by Aspden (Litherland et al., 1990). The Río Quishpe-Río Basancel mineralization was discovered by Sr. Echeverría of Maguazo and is being exploited by Weldorado Inc. Ecuador. All other mines and prospects in the Río Alao/Condorazo areas have been prospected during colonial to recent times out little development or production has taken place and little information has been published concerning the mineralization.

2. ECONOMIC GEOLOGY OF MINES AND PROSPECTS

2.1 Mina San Bartolomé and surrounding area

The San Bartolomé mine is located 1 to 1.5 km N and NW of the town of the same name at an altitude of between 2800 metres and 3300 metres. The mine is presently owned and operated under a joint venture agreement between Banguet Corp. Canada Ltda. and Armenonic del Ecuador. The mine area has been extensively and intensively explored by several organizations (INEMIN-Misión Belga, 1988). Mineralization occurs within fine- to coarse-grained Tertiary andesitic porphyry lava flows thought to be underlain by meta-andesites of the Alao-Paute subdivision (Alao division).

The mine has been explored by surface and underground drilling (6800 metres), exploration galleries (1600 metres) and surface trenches (200 metres), by United Nations projects between 1969 and 1978 and this work has been continued on several mine levels by the mining companies.

Mineralization is complex and includes sphalerite, pyrite, marcasite, galena, chalcopyrite, sulphosalts, arsenopyrite, native arsenic, tetrahedrite, pyrrhotite, boulangerite, polybasite, pearceite, sternbergite, pyrargyrite, freieslebenite and native gold. Gangue minerals are quartz, calcite, opal and adularia. Hydrothermal alteration includes strong argillization with quartz, sericite, chlorite, calcite, pyrite and tourmaline. Some alteration may be related to deep weathering.

Between 1969 and 1972 the United Nation projects reported reserves of 23.5 MT at >2 oz/T silver and 1.0 MT at 10 oz/T silver. Between 1976 and 1978 94.192 T of reserves were reported assaying 22.93 oz/T silver; 1.99% zinc; 0.68% lead and trace gold and cadmium (INEMIN-Misión Belga, 1988).

The present owners report reserves of 100000 MT at 20 oz/T silver, and a 100 T.P.D. mill is presently under construction.

Mineralization is hosted within fracture veins (5 to 10 cm wide) and veinlets. Bifurcations and horse-tails are common. Veins are of the steep and flat types and trend dominantly ENE. Two major NE to NNE-trending faults occur in the mine areas.

Mineralization is complex polymetallic epithermal vein-type, hosted by young volcanic rocks. Economic potential is good and exploration is presently being extended towards the eastern (Shunaste) area.

2.2 Río Paute at location Quebrada Totora Yacu

At least two narrow beds of concordant pyrite-bearing black shales occur within the turbiditic Maguazo subdivision a few tens of metres east and west of Quebrada Totora Yacu; altitude is 2280 metres. The turbidites are intercalated with metamorphosed volcanic flows/tuffs and breccias. There may be potential for volcanogenic massive sulphide mineralization in such lithologies but the pyrite-bearing black slates are not considered economically significant at this stage. Mineralization is considered to be syngenetic and associated with anoxic black shales.

2.3 Mina Peggy and surrounding area

The mineralized area is located around the Mina Peggy about 5 km SSE of the town of Sigsig at an altitude of 2400 to 2800 metres. The area has been described by several organization and individuals (INEMIN-Misión Belga, 1988; Clarke, 1989; Litherland et al., 1990). Country rocks comprise strongly deformed/mylonitized megacrystic biotite granite, quartz-sericite schist and mylonite of the Tres Lagunas subdivision (Loja division; Litherland et al., 1990).

Deformation is attributed to shearing associated with the Baños front. A suite of young undeformed quartz-feldspar porphyry (rhyolite?) dykes and stocks intrudes the older lithologies and crosscuts their pervasive fabric. A large (300 to 400 metres diameter) intrusive breccia pipe and smaller breccia dykes occur in the area. Mine development includes adits in the Peggy vein as well as several prospect adits and pits in the area. The remains of an ore processing plant can be found near the mine. Placer gold mining is presently in operation in the Río Santa Bárbara.

Mineralization is complex with the following ore minerals reported: chalcopyrite, pyrrhotite, arsenopyrite, pyrite, marcasite, stannite, cassiterite, sphalerite, native bismuth, bismuthinite, wolframite and galena. Assay values reported for the Peggy mine ore are: 7.36% copper, 170 ppm silver, 0.6 ppm gold.

Gangue minerals include quartz, tourmaline and carbonates. Hydrothermal alteration is dominated by medium to strong argillization with some silicification and tourmalinization.

A wide (35 metres) exposure of the intrusive breccia pipe was observed in roadcut 1.5 km to the north of the Peggy mine. The breccia is dominated by country rock fragments. The breccia-hosted mineralization has been described (Clarke, 1989) and contains pyrite, arsenopyrite, sphalerite, galena, marcasite, chalcopyrite, pyrrhotite, stannite, tetrahedrite and quartz.

The dominant structure in the country rocks is a foliation trending N50° to 70°E. The Peggy vein or breccia zone is about 20 metres thick and trends N45°W dipping SW at 80°.

Mineralization at the Peggy Mine is complex polymetallic vein/stockwork and mineralized breccia probably related to the young porphyry intrusions. Mineral potential is considered to be good, particularly with respect to concealed vein-stockwork, breccia-hosted and porphyry-type mineralization.

2.4 Pilzhum

The Pilzhum mine area is located about 16 km from Azogues near the Taday road at an altitude of 3400 to 3765 metres. The mine and surrounding area have been examined by several individuals and organizations (INEMIN-Misión Belga, 1988). The country rock is a quartz-andesite or dacite porphyry stock of upper Tertiary or Quaternary age. Intrusive breccia is also present. Mine development comprises more than 600 metres of galleries and the remains of a mineral processing plant are visible. Ore mineralization includes pyrite, chalcopyrite, galena, sphalerite, enargite, tetrahedrite, proustite, bornite, chalcocite and covellite. Reported ore grades are silver 1500 g/T; gold 3.2 g/T, and copper 2%. Gangue minerals are quartz and baryte. Hydrothermal alteration is mostly argillic, and is particularly strong adjacent to veins. Silicification and sporadic propylitic alteration also occurs.

Regional structural control of the deposit has been related to the southward extension of the San Antonio fault (Litherland et al., 1990). Locally, mineralization occurs within 19 to 23 known veins occupying a 3 km by 2 km zone. Dominant vein orientations are N20°E (dip subvertical), N80°E (dip subvertical or steep N), and N45° to 70°E (dip subvertical or steep S). The principal veins are 170 metres to 600 metres in length (INEMIN-Misión Belga, 1988). Mineralization is complex polymetallic epithermal vein-type, hosted by a porphyry intrusion. The mineralized system is large and economic potential is considered good for the discovery of further veins as well as breccia-hosted and porphyry-type mineralization.

2.5 Tampanchi

The Tampanchi mafic-ultramafic complex is located east of Taday and immediately west of the junction of the Río Pindilig and Río Paute. Outcrop varies in altitude from about 2200 metres to 3640 metres. The complex has been studied by Pozo (1990), Litherland et al. (1990) and recently by a mining company with interest in platinum mineralization. Gold and platinum concessions were granted in the vicinity earlier during this century (Navarro, 1986).

The intrusive complex is approximately oval in shape with dimensions of 8 km × 4 km. It intrudes greenschists of the Alao-Paute subdivision (Alao division). The intrusion is reported to be zoned with a core of ultramafic serpentinites and olivine clinopyroxenites surrounded by pyroxenites displaying cumulate textures. These are surrounded in turn by hornblendites and hornblende gabbros and, finally, fine-grained hornblende basalts (Litherland et al., 1990).

Known mineralization is restricted to alluvial gold and platinum recorded from streams draining the complex. However, anomalous values for copper, nickel, chromium, gold and platinum-group-metals have been obtained from stream sediments, soils and rock samples from the complex.

Mineralization is probably in the form of precious metal-bearing sulphides disseminated, or in veins/layers, within the intrusion. Mineralization is probably magmatic segregation-type, typical of layered mafic intrusions e.g. Bushveld, Sudbury, Muskok and Alaskan-type intrusions. This type of mineralization tends to be large tonnage and low-grade, therefore, the economic potential of the Tampanchi complex is probably restricted because of its relatively small size.

2.6 Río Quishpe/Río Basancel

This gold-producing area is located in the eastern headwaters of the Río Quishpe, 7 km east of Pungalapamba at altitudes of between 3800 metres and 4200 metres. Gold mineralization was discovered in the area by Sr. Echeverría, a prospector from Maguazo. The concession is currently held by Weldorado Inc. of Quito-Ecuador, and a small placer mine is in operation. The mine is operated by 2 to 4 miners washing gold from coarse colluvial material in a steep valley. Country rocks in the area are dominated by fresh and altered hornblende-biotite granodiorite possibly the northern extension of the Alao granite, fine-grained grey porphyries are also common in the area.

Primary mineralization, where exposed, comprises oxidized and gossanous quartz veins with pyrite, pyrrhotite, chalcopyrite and possibly other sulphides, as well as free gold. Silicification is common in fine-grained grey lithologies which usually contain disseminated pyrite.

Strong shearing and jointing are common in places within the granodiorite. Sometimes the fine-grained grey porphyry is cut by a network of quartz veinlets. All oxidized vein samples and colluvial samples within the area of granodiorite exposure pan free gold. The gold is widely distributed but not spectacularly rich, usually yielding a few to tens of colours per pan. Gold mineralization seems to be associated with the mineral veins cutting the granodiorite and a genetic connection may exist. Certainly, Au mineralisation is closely spatially associated with the granodiorite outcrop. The area of gold producing granodiorite exposure is approximately 1.5 km × 1.5 km. Alluvial/colluvial gold can be obtained at least 2 km downstream in the Río Quishpe. Structures are brittle/ductile. Mineralization is considered to be intrusion-hosted polymetallic hydrothermal vein type and economic potential is thought to be good.

2.7 Río Alao-Condorazo area

This section describes several small mines and prospects in the Río Alao valley and surrounding area and the Condorazo area to the northeast.

2.7.1 Mina Agua Santa

The Mina Agua Santa is located in the Quebrada Agua Santa on the south bank of the Río Alao about 2.5 km upstream of the Pungalapamba bridge and at an altitude of 2855 metres. Country rocks are rhythmically banded black shales and quartzites of the Cebadas subdivision (Guamote division). These rocks are particularly well exposed at the junction of the Quebrada Agua Santa and the Río Alao.

Mine development comprises a single horizontal adit, 5 metres long trending 286° within a fault. At 2845 metres, and below the adit, a mineralized fault with pyrite and green (malachite) coloured efflorescent minerals is exposed. The fault trends approximately north-south and dips steeply to the east. The hanging wall is a competent quartzite and the footwall comprises strongly folded black schists/shale. This mineralisation is considered to be hydrothermal vein or lode of unestablished genetic origin. Economic potential is considered to be fair.

2.7.2 Mina Nueva (Siminguis)

This mineralization is located in the Quebrada Siminguis on the south bank of the Río Alao about 3 km upstream from the Pungalapamba bridge at an altitude of 2895 metres. Country rocks are black and grey schists and quartzites of the Cebadas subdivision (Guamote division; Litherland et al., 1990).

Mineralization is dominantly massive pyrrhotite, possibly with some pyrite and chalcopyrite, associated with narrow quartz veins, and, in the main exposure, a porphyritic dyke containing disseminated sulphides (pyrite?). The main exposure is visible as a strongly oxidized and iron-stained zone approximately 3 metres wide and 4 metres high in the north wall of the quebrada. A similar, but smaller, exposure occurs in the quebrada at 2910 metres. Mineralization is considered to be hydrothermal vein or contact metasomatic in origin and economic potential is thought to be poor.

2.7.3 Mina Imanante

The Mina is located about 0.5 km south of the summit of Cerro Imanante on the northern slopes of the Río Alao valley at an attitude of 4010 metres. The country rocks are fine-grained homogeneous grey-white volcanic or minor intrusive rocks sometimes showing randomly orientated feldspar crystals. The outcrop has an angular blocky fracture. These rocks may be members of the Maguazo subdivision (Alao division) of Litherland et al. (1990).

In this locality the rocks are cut by narrow (2 mm thick) veinlets of a hard silvery-grey metallic mineral (arsenopyrite?) which forms platy crystals. The mineralization is considered to be hydrothermal vein and possibly intrusive-hosted-type. Economic potential is not considered high but this mineralisation could indicate concealed mineral potential.

2.7.4 Mina Maguazo

This mineral showing is located in an exposure on the Maguazo-Upper Peltetec village road about 0.6 km west of Maguazo at an altitude of 3140 metres. Copper mineralization has previously been reported from this location (Litherland et al., 1990). Country rocks comprise banded turbiditic greywackes of the Maguazo subdivision (Alao division). Mineralization comprises narrow (cm-scales), oxidized and iron-stained, boudinaged quartz veins carrying sulphides and some green malachite. In addition, there is a yellow-brow weathering dyke of intrusive breccia. Fresh samples are dark grey-black in colour and have a porphyritic texture with grey green phenocrysts and ovoid blebs of granular pyrite. Mineralization is hydrothermal vein and intrusion breccia with disseminated sulphides. Mineralization is itself economically insignificant but may indicate potential for further concealed mineralization in the vicinity.

2.7.5 Mina Curiayana

This mine is located on the ridge separating Quebrada Minas and Quebrada Shiga 3.6 km to the east-north of the town of Alao at an altitude of 4155 metres. Country rocks are strongly foliated, and sometimes refolded, fine-grained, grey-green metavolcanics of the Alao-Paute subdivision (Alao division). Foliation in the area trends N24°E and dips west 48°. Mine development comprises a decline 2 to 3 metres deep following two narrow quartz veins (15 cm wide) which cut the schist fabric at a large angle. The veins comprise coarse comb-textured quartz with vuggy terminations. Sulphides commonly occur near the walls of the vein and include pyrite, chalcopyrite, sphalerite and galena. Free gold was obtained from the oxidized veins. The veins occupy brittle fractures trending N77°E dipping south 80°. Wallrock alteration is absent or inconspicuous, but the veins are oxidized and show brown iron staining. This mineralization is considered to be polymetallic hydrothermal vein-type of unknown genetic origin. No porphyry intrusions were observed in the vicinity.

A few hundred metres to the north of the Mina Curiayana, along the ridge, a small area of brown, iron-stained sericite schist with disseminated cubes of pyrite outcrops. This type of occurrence could be related to epigenic or syngenetic mineralization.

2.7.6 Mina Cacadron

This mineralization forms a conspicuous brown, iron-stained screen on the summit of a small peak located south of Laguna Cacadron 4.8 km to the east north-east of the town of Alao, altitude is 4215 metres. Country rocks are greenschist metavolcanic rocks of the Alao-Paute subdivision (Alao division). Mineralization comprises a vein of pyrite-bearing porous quartz occurring as oxidized grey-yellow-brown coloured outcrop trending approximately N87°E and dipping vertically. The vein outcrop is 4 to 5 metres wide and is discordant to the local foliation in the schists (N36°E dip 80° west). Near the summit loose blocks of brown-black porous gossan occur. Mineralization is associated with brown-stained white-coloured zones of sericite schist with disseminated pyrite. The schists display complex folding with ribs and veinlets of silicification common. The sericite schists occur as several zones distributed for 100 metres along the summit ridge.

2.7.7 Mina Cruzacta

Mina Cruzacta is located on a ridge east of Quebrada Cruzacta 3.6 km to the southeast of the town of Alao at an altitude of 4150 metres. Country rocks are greenschists meta-volcanic rocks of the Alao-Paute subdivision (Alao division). Mine development includes a decline greater than 20 metres deep, and a surface pit 30 metres long. There may be more underground development in the mine but access is difficult. Mineralization comprises a narrow sulphide-rich sheared vein or mineralized horizon in brown stained and hydrothermally altered greenschists. Narrow (<1 cm wide), discordant, brown coloured and oxidized cross-veins cut the wallrock. The walls of the decline follow the trend of the mineralized zone at N7°E dipping west 65°. At the southern and of the surface pit gossanous debris and a large block of green malachite-stained ribs 15 cm to 50 cm wide trending N163°E, dipping west 60°. The pit trends N159°E. This mineralization is probably epigenetic hydrothermal vein polymetallic-type but exposure is poor. Economic potential is considered fair.

2.7.8 Mina Alao

Mina Alao is located 3.5 km east of the town of Alao in a roadcut on the north side of the Alao valley at an altitude of about 3200 m. Copper mineralization has previously been recorded at this site (Litherland et al., 1990). Country rocks are greenschist meta-volcanic rocks of the Alao-Paute subdivision (Alao division). The mine comprises a horizontal adit 6 metres long, trending N7°E. The adit is driven into quartz-sericite schist which outcrops as brown-yellow iron stained, white sericite schist with disseminated pyrite. The altered/mineralized schist outcrop along the road section for 65 metres. Similar altered schist outcrop is clearly exposed at the south bank of the Río Alao and is probably an along-strike extension of the mineralized zone at N5°E. Foliation is complex with a dominant trend of N160°E dip west 80°, and is re-folded within the mineralized zone. Mineralization is probably epigenetic and related to brittle/ductile structures. This zone may be related to mineralization of the Mina Cruzacta. Economic potential is considered fair to good.

Similar mineralization comprising disseminated pyrite in greenschist and sericite schist was observed in iron-stained rock fragments in the north-trending section of the Alao valley road.

2.7.9 Mina Condorazo

Mina Condorazo is located 18 km north-northeast of the town of Alao and 1.5 km west of the 4458-metre peak of Cerro Condorazo at an altitude of between 4070 and 4080 metres. The mine has previously been described, primarily as a silver mine (Navarro, 1986; Goossens, 1972; Litherland et al., 1990). Country rocks comprise sheared and foliated semipelitic mica schist, garnet schist and granite of the Tres Lagunas-Agoyán subdivisions (Loja division). Mine development comprises an adit 8 metres long trending N40°E in the northern outcrop of the vein and an adit/decline in the main outcrop of the vein to the south. Both adits were flooded. A small water-filled pit is located towards the south of the vein with a trench trending due north. Mineralization is dominated by a thick (up to 2 metres wide) vein of milky white quartz which outcrops as an upstanding ridge. The vein is somewhat discontinuous but can be traced along strike for more than 200 metres. Vein trend is approximately N170°E dipping 74°W. Large irregular masses of oxidized pyrrhotite occur in the vein sporadically and inclusions of granular granite country rock occur. The walls of the vein are strongly sheared granite, with a vein-parallel fabric but the vein is generally discordant, with respect to the regional fabric. Yellow-weathering, coarse carbonate vein material sometimes occurs. Waste mineralized samples of the vicinity of the summit adit are variable in composition and include brown altered granite with disseminated pyrite; white, granular granite with disseminated galena; and pyrite and massive pyrite-pyrrhotite. Wallrock waste from the north adit comprises altered schist and granite, the latter bearing orange coloured weathered dolomite/ankerite micro-veinlets. Mineralization is considered to be hydrothermal vein polymetallic-type related to brittle/ductile structures. No porphyry intrusions were observed in the vicinity. Mineral potential is considered fair.

2.7.10 Mina de Pilas

Mina de Pilas is located 15.6 km north-northeast of the town of Alao on the eastern slopes of the Cordillera de Pilas at an altitude of between 4155 and 4185 metres. Country rocks comprise greenschist and sericite schist meta-volcanic rocks of the Alao-Paute subdivision (Alao division). Mineralization comprises massive, granular and bedded pyrite interbedded with granular quartz and sericitic schist horizons and enveloped in a footwall of pyrite-bearing sericite schist and a hanging wall of green chloritic schist, also with disseminated pyrite. The pyrite bed is at least 7 metres thick and about 200 metres long and is folded with green chloritic schist in the core and white sericite schist in the envelope. The fold closes to the south and dips steeply west. The thickness of the sericite schist is undetermined but exceeds tens of metres. Locally foliation trends N173°E dipping 74°W but bedding in the pyritic horizon mimics the geometry of the fold. The pyrite horizon is cut in places by small epigenetic quartz veins and a dyke or vein of granular pyrite was observed to intrude the sericite schist footwall. Both the sericite schist and chlorite schist exhibit strong and complex deformation textures (folding).

This mineralization represents volcanogenic massive sulphide deposition and is a very encouraging indication for potential polymetallic copper-zinc-lead ±Au ±Ag mineralization in the vicinity, and elsewhere within the Alao-Paute subdivision. Economic potential is considered very good.

3. METALLOGENESIS AND MINERAL POTENTIAL

Mineralization examined during this work can be classified as follows:

i) Porphyry-related polymetallic veins.

ii) Polymetallic veins in metamorphic rocks.

iii) Disseminated (syngenetic) pyrite in black shales/schists.

iv) Volcanogenic massive sulphide mineralization.

v) Magmatic sulphide/PGM mineralization in mafic/ultramafic intrusions.

The porphyry-related polymetallic veins (San Bartolomé, Mina Peggy/Sigsig, Pilzhum and possibly Río Quishpe/Basancel) probably belong to larger hydrothermal systems as indicated by the associated widespread hydrothermal alteration and mineralization. Economic potential within these areas is generally good with the possibility of further vein mineralization, as well as related breccia pipe-hosted, porphyry-type and/or replacement/skarn mineralization.

The polymetallic veins in metamorphic rocks are generally solitary and isolated with little potential for economic tonnages but favourable structures, especially in greenstones, ultramafic rocks and turbidites (Alao-Paute, Peltetec and Maguazo-type formations) could host valuable shear zone lode gold veins. This is supported by the occurrence of intensive quartz veining associated with the Baños front in the Río Alao area (this study and Litherland et al., 1990).

Disseminated (syngenetic) pyrite in black shales/schists (e.g. Río Paute) is not considered economic, but the close spatial association between the deep-water sediments with greenstone meta-volcanic lava flows, tuffs and breccias could indicate potential for volcanogenic massive sulphides within the Maguazo and Alao-Paute subdivision lithologies.

The volcanogenic massive sulphide potential of the Alao-Paute subdivision greenstones has been confirmed by the Mina de Pilas mineralization. Although not economic itself, this mineralization represents an ore-forming environment favourable to the formation of polymetallic deposits. Mina de Pilas could, in fact be part of such a deposit. Economic potential is very good and strenuous follow up exploration is strongly recommended.

Magmatic (Cu-Ni-Fe) sulphides, chromium and platinum-group metals (PGM) mineralization may be related to mafic/ultramafic intrusions of the Tampanchi type but the small size of these intrusions is not economically encouraging. Similar mineralization could be related to Peltetec subdivision ophiolites and these should be examined.

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Dr. Richard A. Jemielita

No. 5652

QUITO, JULY 23, 1991

TO : ING. WILSON SANTAMARÍA

FROM : DR. RICHARD JEMIELITA

SUBJECT : Commission report for the areas of: Isimanchi, Malacatus, Jimbura-Amaluza, Yangana, San Antonio, Saraguro, Sigsig, Pilzhum, from May 05 to 29, 1991.

1. INTRODUCTION

1.1 Project context

The Cordillera Real Geological Project, a technical cooperation agreement between the governments of Ecuador and Great Britain, in its third phase includes the subproject "Economic Potential of the Cordillera Real".

For this reason, a field commission was carried out from May 05 to 29, with the purpose of continuing the geo-mineralogical works and studies of the outcrops in the subproject's areas of interest.

1.2 Objective

To continue the geo-mineralogical research and mineral evaluation work in the belt that comprises the Cordillera Real of the Andes, in order to determine its future economic potential aimed at national mining development.

1.3 Assigned personnel

To carry out this work, the commission was composed of:

Dr. Richard Jemielita (ODA/BGS)

Egdo. Johnson Bolaños (INEMIN)

Sr. Manuel Célleri (INEMIN)

1.4 Transport

Land Rover Jeep, license plate AT-0274, belonging to the British Mission.

1.5 Detailed activities

Month	Day	Traverse
	05	Quito-Cuenca (Driver)
	06	Quito-Cuenca (Technicians)
	07	Cuenca-Amaluza-Loja
	08	Loja-Jimbura-Loja
	09	Loja-Palanda
	10	Palanda-Río Isimanchi-Palanda
	11	Palanda-Río Numbala-Valladolid
	12	Valladolid-Ventanilla-Yangana
	13	Yangana-Suro-Loja
	14	Loja-Quebrada Salado Negro-Las Aradas
	15	Las Aradas-Río Pindo-El Tingo-Loja
	16	Loja-Quebrada de Minas-Vilcabamba
May	17	Vilcabamba-Río Malacatus-Vilcabamba
	18	Vilcabamba-Río Calanuma-Loja
	19	Loja-Santiago-Loja
	20	Loja-Río Aguarnupa-Loja
	21	Loja-Potrerillos-Cuenca
	22	Cuenca-Oña-Nabón
	23	Nabón-Conejo Huaycu-Cochapata
	24	Cochapata-Río Shincata
	25	Río Shincata-Río Betas
	26	Río Betas-Las Palmas
	27	Río Las Palmas-Río Conventillo
	28	Río Conventillo-Rodeo-Cuenca
	29	Cuenca-Quito.

1.7 Access

Some sections of the study areas are accessible by vehicle (Land Rover), such as the Sigsig zone. However, in high sections of the Cordillera that generally exceed 3500 meters above sea level, it is necessary to use mules and go on foot to reach the points of interest; such is the case, for example, at the Isimanchi River.

2. GEOLOGY

2.1 Río Isimanchi area (Map 2a)

The part of the Río Isimanchi area examined lies about 17 km south-southeast of the town of Jimbura in the south of Ecuador, near the border with Perú. Access is by mule and on foot along the Jimbura-Zumba road which is inaccessible to motor-vehicles because of several landslides. Altitudes in the study area range from 2650 metres to 3500 metres and the local topography is steep. Slopes are covered in thick forest and the weather is misty and wet and often cold. The higher areas have páramo-type vegetation. The area was previously traversed by Aspden (Misión Británica), who reported the occurrence of anomalous Au, Ag, Cu, Zn, Mo and Sn in stream sediment samples.

Rocks exposed along the access route comprise mostly granodiorites and diorites of the Portachuela batholith. In the study area epidotized granodiorite is common. Altered/sericitized schist (sheared granodiorite) occurs, along with biotite and feldspar-phyric porphyry, and kaolinized/pyritized porphyry. Grey, homogeneous, silicified porphyry occurs with disseminated pyrite, and a pyrite-bearing quartz vein was noted. In quebrada Churrera Negra an interesting outcrop of pyrite cemented feldspar-phyric breccia occurs and has been prospected by shallow pits in places. A prominent red-coloured zone of mineralized rock is exposed by a landslide 0.5 km east of the junctions of the Río Isimanchi and quebrada Los Colorados.

River boulders in the Río Isimanchi comprise epidotized granodiorite, biotite-quartz-feldspar porphyry, granitoids and dark grey-green, fine-grained schists. Some brown iron-oxide stained and/or pyrite-bearing schists and rocks (possibly skarns) were noted. Streams (quebrada Golpadero, quebrada Calderon, quebrada 25 de Diciembre), draining into the Río Isimanchi contain boulders of mica schist or gneiss and xenolith-rich granodiorite intrusion breccia.

The area is essentially a batholithic granodiorite-diorite terrain with adjacent schists. Later hypabyssal porphyries intrude the batholith. Both the batholith and the porphyries are mineralized in places with epidote, sericite/kaolinite and pyrite being relatively common. Stream sediment anomalies indicate potential for Au, Ag, Cu, Zn, Mo and Sn mineralization which could be related to plutonic rocks of the Portachuela batholith, or later porphyries, or both. Exploration will be hampered by the steep and rugged forest terrain and wet climate.

2.2 Jimbura-Amaluza area

This area comprises rocks of the Sacapalca Formation of volcanics and volcanoclastics and is not strictly within the area of the Cordillera Real study. Nevertheless, attention should be drawn to the extensive and intensive hydrothermal alteration commonly expressed as white-yellow-red zones of clay altered rocks in this area and which may have epithermal-type mineral deposit potential. It is recommended that these rocks be examined closely in the future.

2.2.1 San Antonio de las Aradas (Map 2b)

A previous (U.N.) stream sediment tungsten anomaly was reported in the quebrada Salado Negro about 5 km east of the town of San Antonio de las Aradas. Access was made along foot paths. Altitudes in the area of interest range from 1600 metres to 2000 metres. Local topography is moderately steep and mostly in open agricultural land. Local rocks are black and grey graphitic mica schists of the Chigüinda subdivision (Loja division) of Litherland et al. (1990). Quartz veins up to 1 metre thick, and sometimes with brown iron-oxide staining, are common. Red-white alteration, similar to that seen in Jimbura-Amaluza, is also relatively common in the area. The quebrada Salado Negro contains boulders of medium-grained granodiorite, and massive white vein quartz, sometimes with mica schist wallrock attached. Mica schist comprises most of the fine-grained boulders. Lineation trends measured locally are around N169°E with plunges of 22° to the south. Stream sediment pan concentrates were taken. A local guide claimed that gold had been won from the quebrada Guineo nearby to the northeast, and that old Inca workings are known in the páramo country to the east and southwest. Tungsten in stream sediments may be related to granites and/or hydrothermal veins in the area and may be in the form of wolframite or scheelite or both. This awaits laboratory confirmation. The iron-oxide-stained veins may have potential for gold mineralization.

2.2.2 Yangana (Map 2c)

The area examined lies between 0.5 km and 2.0 km north-northeast of the town of Yangana between the altitudes of 1845 metres and 1960 metres. Access is by a rough footpath along the Río Chinguana. The local topography is moderately steep with a mixture of agricultural land and scrub, with thick forest at higher altitudes. Exposed rocks are mostly black graphitic slates and schists of the Chigüinda subdivision (Loja division) of Litherland et al. (1990). These are extensively and unconformably overlain by sediments of the Mio-Pliocene Quillollaco Formation. To the southeast of Yangana, at the junction of the Río Chiriguana and Río Maco, river boulders are dominated by granite, granodiorite and granodiorite schist as well as black schist (some with brown iron-oxide staining). Traversing eastwards up the Río Chiriguana similar lithologies were encountered as well as silver-grey, grey and green schists, and strongly iron-oxide-stained boulders of medium to coarse-grained, granular, sugary (altered) granodiorite with disseminated pyrite. Boulders of white "bull" vein quartz were fairly common. Large blocks of fine-grained grey (silicified) rock are also fairly common. Vuggy quartz veins, sometimes with brown iron-oxide staining, cut some of the lithologies described. A few rounded boulders of very coarse-grained, black tourmaline-bearing granite pegmatite were encountered. One pegmatite sample was seen to be cutting across the foliation of a biotite-schist.

A small mine was visited, apparently worked for gold in pyrite-bearing quartz veins cutting black graphitic schist. A horizontal adit has been driven south at approximately N10°E in steeply eastward-dipping dark grey phyllites. The mine was inaccessible (Locked gate) but the mine dump yielded centimetre-scale white vein quartz containing a little yellow carbonate. Veins appear to be discordant to the foliation. There are considerable indications of mineralization in this area, mostly related to granodiorite/granite magmatism. The source area of the mineralized river boulders could repay more detailed examination.

2.2.3 San Antonio road (Map 2c)

This area lies about 5 km southeast of Yangana and is accessible by four-wheel-drive vehicle. Rocks are best exposed in the road cut, otherwise the area is covered in thick forest. Country rocks are medium to coarse-grained biotite quartz-feldspar schists with a strong foliation. Yellow-black iron-oxide staining and moderately abundant disseminated pyrite occurs in schist exposed in road cuts for a distance of about 0.5 km. Some surfaces expose vuggy quartz veins and at one locality, molybdenite and a yellow-green powder (possibly ferrimolybdite) were noted coating fracture surfaces. Mineralization is vein and disseminated types and may be related to faulting and nearby igneous intrusions.

2.2.4 Malacatus-Cerro Minas (Map 2d)

The Cerro Minas is a conspicuous red coloured, cone-shaped hill located 3 km southwest of the town of Malacatus. Country rocks in the vicinity of the hill include fine-grained grey mica schist, biotite schist and granodiorite (Loja division) and gritty siltstones (Miocene San Cayetano Formation). The area is wrongly mapped on the Gonzanamá 1:100000 scale geology map as volcanic rocks of the Loma Blanca Formation. The Cerro Minas itself comprises dominantly medium-grained, biotite mica schists and granodiorite. These rocks are variably hydrothermally altered and exhibit the red colouration typical of the hill. Float fragments found on drilling access roads on the east side of the hill include vuggy quartz-cemented breccia with altered and brown iron-stained porphyry fragments, fine-grained vein quartz with abundant fine-grained pyrite, crystalline purple fluorite, vuggy crystalline vein quartz, white altered porphyry, flow banded rhyolite, green porphyritic andesite and massive brown ferruginous gossan.

On the north east side of the Cerro Minas a shallow decline cuts intrusive breccia composed of coarse, altered mica schist fragments cemented with quartz. Green (copper) efflorescent minerals are common, along with iron and manganese oxides. The intrusive breccia is exposed above and below the decline over a width of ca. 180 metres and an altitude of at least 30 metres. The intrusive breccia is complex and composite and is strongly veined, hydrothermally altered and mineralized. The section above the decline has been exposed by trenching.

The rocks exposed by the exploration trench (45 m wide) comprise variably altered intrusive breccias with strong red-brown iron-oxide staining. black manganese oxides and narrow (<1 cm wide) vuggy quartz veins. The breccias range from fine to coarse and are both clast and matrix-supported types. Clasts include porphyry and, more commonly, fine-grained mica schist. Quartz veins and silicification are common in places. Sulphide mineralization is dominantly pyrite and sphalerite. At one locality sphalerite coats breccia fragment in an open-textured, vuggy, clast-supported breccia. Fractures and veins tend to form a parallel group in this exposure. A fine-grained grey-green, granular intrusive dyke cuts the exposure at one locality and contains irregular patches of purple fluorite. Mineralization is epithermal vein and intrusive breccia type, probably related to a concealed porphyry intrusion(s).

2.2.5 Río Masa

This river flows westwards from the Cordillera Oriental de los Andes and was examined about 2 km north east of the town of Masanamaca, about 0.5 km upstream of the junction with the Río Santa Cruz. Local topography is steep and mostly in agricultural land. Country rocks are east-dipping black-grey coloured schists and inter-bedded quartzites of the Chigüinda subdivision (Loja division). Stream boulders are dominated by granite/granodiorite, biotite schist, black-grey coloured schists and, less commonly, large blocks of white "bull" vein quartz.

The Río Santa Cruz about 300 metres upstream of the Río Masa contains boulders of medium-grained, granular granodiorite with quartz lenses and aligned xenoliths defining a fabric. Other lithologies include biotite-muscovite granite, massive white vein quartz, biotite schist or gneiss, quartzite, green leuco-diorite and less commonly green andesite porphyry. One white block of quartz feldspar pegmatite was noted. Mineralization is expressed by some fine-grained pyrite noted in a quartzite and weak to moderate brown iron oxide staining on some granodiorite boulders. Gold has apparently been won from the quebrada de Minas, a tributary of the Río Masa, but this area was not visited.

2.2.6 Loja-Río Malacatus

The Río Malacatus south of Loja is worked for alluvial gold, and tributaries of the river on both banks are reputed to be auriferous. Gold was examined from a location about 5 km south of Loja. The gold comprises rather waterworn discs or plates, as well as grains, with pitted surfaces. The gold is deep yellow in colour and the local miners estimate a production of 3 g per day to be reasonable. This area will be revisited for more detailed examination.

2.2.7 Santiago-Quebrada de Minas (Map 2e)

Quebrada de Minas was accessed on foot via Quebrada El Sauce, a distance of 4.5 km. Altitudes range between 2400 metres and 3000 metres. Local topography is moderately steep with agricultural land and thick forest at lower and higher-altitudes respectively. Stream boulders in both quebradas are dominated by medium to coarse-grained (San Lucas) granodiorite and grey green andesite with some coarse volcanic breccias. The upper stretch of the Quebrada de Minas was sampled by panning but the yield of heavy minerals was poor and no visible gold was noted. The area around the town of Santiago displays extensive white-yellow-red hydrothermally altered volcanic rocks which should be investigated for potential epithermal mineralization. Otherwise, no conspicuous signs of mineralization were noted.

2.2.8 Lomo del Loro (Map 2f)

1.5 km to the north of Lomo del Loro and about 6 km south of the town of Saraguro along a new road, a spectacular white-yellow-red coloured, hydrothermally altered and mineralized dacite porphyry intrusion and associated intrusive breccias are exposed in the road-cut.

At least four different types of intrusive breccia are exposed:

i) Grey coloured, medium-grained, matrix-supported breccia with angular, pink-coloured, altered, quartz-phyric dacite/rhyolite and feldspar-phyric porphyry, together with smaller fragments of fine-grained black schist. The matrix comprises fine-grained rock flour dominated by altered feldspar. This breccia contains fine-grained disseminated pyrite and is exposed for about 120 metres horizontally.

ii) Fine to medium-grained, matrix-supported, intrusive breccia with a fine-grained black matrix and grey dacite clasts. This breccia forms small, irregular dikes and veins, usually cutting dacite porphyry.

iii) Medium to coarse-grained intrusive breccia. This breccia is clast supported with fragments of porphyry and black schist. The breccia is usually soft, weathered and haematized, and is exposed horizontally for about 30 metres.

iv) Very coarse grained, clast-supported breccia with altered dacite fragments in a fine-grained rock flour matrix. Pyrite is commonly disseminated within fragments and coats their surfaces. This breccia is exposed horizontally for about 30 metres.

In addition, the road-cut exposes variably altered/silicified quartz-feldspar-phyric dacite porphyry which is commonly oxidized and stained red, yellow and brown with iron oxides. The porphyry is exposed at two localities over horizontal distances of 160 metres and 375 metres. At the western end of the road-cut the dacite porphyry exhibits an intrusive contact against mica-schists, the latter probably a member of the Agoyán subdivision (Loja division).

Mineralization comprises disseminated sulphides in porphyry intrusions and intrusive breccias. Sulphide bearing quartz veins were also noted. This roadcut exposes new and previously undocumented mineralized porphyries and breccias and should be examined in greater detail.

2.2.9 Cerro Puglla (Map 2f)

On the south-east side of the Cerro Puglla about 3 km southeast of the town of Saraguro a roadcut on the new Loja road exposes a red-yellow-grey coloured clay soil and rock fragment-rich slope containing a variety of mineralized rocks: e.g. grey-green coloured, feldspar-phyric latite porphyry, fine-grained purple-grey coloured silicified rock with disseminated pyrite, fine-grained, dark, grey-purple coloured silicified porphyry with disseminated pyrite (one sample has small breccia veins), green-purple coloured (welded?) tuff with flow banding, a variety of fine-grained granular, silicified rocks with disseminated pyrite, including one sample with medium-grained, pink-coloured, hexagonal plates of alunite; grey-white coloured chalcedonic quartz with altered feldspar and coarse volcanic breccia.

The nature of this deposit is problematical. It could be a volcanic breccia or volcano-sedimentary slump deposit, or a weathered, mineralized intrusive breccia. Nevertheless, the mineralization is significant and occurs within one of the red alteration zones commonly seen in the Saraguro area. Local rocks are volcaniclastics of the Saraguro and/or Tarqui Formations. This mineralization confirms the occurrence of epithermal-type deposits in the area and should be investigated further.

2.2.10 Saraguro Sn-W stream sediment anomaly (Map 2f)

A stream sediment tin-tungsten anomaly, previously reported by the U.N. and Clarke (1989) was examined and resampled. The area of interest lies in the Río Casaturu (misnamed Río Pichanal on the geological and topographical maps) about 11 km east of the town of Saraguro.

Access was by Land Rover and on foot. Local topography is gentle to moderately steep and mostly in agricultural land and altitudes range between 2600 metres and 2800 metres in the area of interest. To the east and at higher altitudes thick forest predominates. Rocks encountered include variably hydrothermally altered volcanic and volcaniclastic rocks, porphyry, and granodiorite intrusions and, to the east, mica schists of the Agoyán or Tres Lagunas subdivisions (Loja division). Along the access path on the north bank of the Río Casaturu prominent large blocks of white "bull" vein quartz were noted.

In the Río Casaturu just west of its junction with the quebrada Artezones, boulders are dominated by fine-grained, purple-grey coloured mica schist, sheared granodiorite (schist), medium-grained, granular granite, volcanic tufts, grey, feldspar-phyric dacite porphyry greenschist, grey fine-grained, granular quartz and white "bull" vein quartz. Some granite boulders have black streaks or veins of a striated black mineral (biotite, hornblende, tourmaline or cassiterite). Stream sediment samples were taken.

Another sample site was examined in the Río Casaturu about 10 metres upstream of the junction with the quebrada Artezones. Country rock at this locality comprises fine-grained, grey-purple mica schist with some brown iron-oxide staining, and a similar suite of lithologies in river boulders to the above location.

A third locality was examined and sampled in the quebrada Artezones about 30 metres upstream of the junction with the Río Casaturu. The river boulders here are dominantly fine-grained, grey mica schist with fewer granitoid boulders than at the previous localities. Some medium-grained grey porphyry and massive white "bull" vein quartz boulders were noted, along with yellow volcanic tuff and sheared silicic schist/mylonite.

It is likely that the tin/tungsten stream sediment anomaly is associated with primary mineralization related to granites in the source area to the east.

2.3 Saraguro area - General observations

The Saraguro area is dominated by lava flows and volcanoclastic rocks of the Eocene? Saraguro formation and Pleistocene Tarqui Formation. A general view over the area reveals numerous areas of red and white hydrothermally altered volcanic rocks. This area should be examined in more detail for epithermal mineral deposit potential.

2.3.1 Río Shincata-Río Betas (Nabón-Cochapata) (Map 2a)

The Río Shincata and Río Betas occupy an area of about 20 km × 8 km to the east of the towns of Nabón and Cochapata. Topography is rather subdued, with flat river terraces and rounded hills, except in the headwaters of the rivers where slopes become steeper. Altitudes in the area of interest range between 3000 metres and 3200 metres. Access is generally good for four-wheel drive vehicles, especially along mine access roads (some new roads have been constructed by Shincata-Bestión mining company). Elsewhere access is good on foot across páramo-type terrain.

The Río Shincata area is famous for gold production and has had a long history of exploitation. Pre-colonial, possibly pre-Inca alluvial workings are common and alluvial mining continues at present. All workings are of the alluvial type and exploit palaeo-river terraces. No workings were noted in active river sediments.

The palaeo-river terraces comprise poorly sorted and poorly to well-bedded quartz pebble conglomerates (unlithified). The conglomerates are generally pure quartz with some rounded black tourmaline pebbles which are used by local miners as indicators of gold bearing material. Gold is generally deep yellow in colour, rather fine-grained, well rounded, and nuggety in shape.

Some terraces comprise polymict conglomerates containing rounded boulders of various types of grey coloured mica schist, medium to coarse-grained granitoids, sheared and brown iron-oxide-stained silicic granular rock with disseminated pyrite, fine to medium-grained dolerites, vein quartz tourmaline pebbles and fine gold.

Many of the alluvial workings are in abandoned ox-bow terraces, but others occur tens of metres above the present river system as palaeo-terraces. The genesis of the pure quartz pebble conglomerates is enigmatic but palaeo-placer gold deposits of similar original composition are well known elsewhere in the world, e.g. the huge gold deposits of the Witwatersrand in South Africa.

Country rocks in the Río Shincata-Río Betas area are dominantly fine to coarse-grained biotite schists of the Tres Lagunas subdivision or possibly the Agoyán subdivision (Loja division), and may be sheared equivalents of the Tres Lagunas granite in some instances. Boudinaged quartz veins were noted cutting the schist basement and numerous float blocks of angular vein quartz, sometimes containing tourmaline, form linear features (delineating veins) crossing the páramo. The quartz-tourmaline association is, therefore, common to the palaeo-river terrace alluvial deposits and the basement veins, and the gold in the former is likely derived from the latter deposits.

In the northern area of the Río Shincata, open pit workings (Mina Rea) expose strongly foliated mica schist overlain by a red-coloured, clay-rich soil (laterite?) containing rounded quartz pebbles and relict, rotted granular (granite) rocks. This soil may indicate a previous episode of humid tropical weathering which would have converted granitoids and schists to clay minerals and iron/aluminium oxides, leaving quartz, tourmaline and gold as residual deposits after erosion. This could account for the genesis of the quartz-tourmaline-gold terrace deposits. More detailed study will be required to test this hypothesis.

The quartz-tourmaline-gold vein association is common in shear zone-hosted lode deposits, e.g. in Archaean greenstone belts worldwide, and in younger deposits such as the Mother lode gold belt in California. Such deposits have not previously been documented in Ecuador. This type of mineralization is commonly associated with extensive faults or shear zones. It is interesting to note that the Río Shincata-Río Betas area is dominated by strongly foliated/sheared mica schists and is part of the Baños front, described by Aspden (Misión Británica) a regionally extensive shear zone with closely spatially associated gold mineralization.

The Río Shincata-Río Betas area has very good potential for alluvial gold mining and there is potential for hard-rock mining in the quartz veins.

2.3.2 Sigsig-Mina Peggy (Map 2h)

The mina Peggy and surrounding mineralized area is located about 5 km south-southeast of the town of Sigsig at an altitude of 2400 to 2800 metres. The local topography is very steep with páramo-type vegetation. The area has been described by several organizations and individuals (INEMIN-Misión Belga, 1989; Litherland et al., 1990; Jemielita, 1991). The area was re-visited to examine the mines and mineralization in more detail.

The alluvial gold workings in the Río Santa Bárbara in the immediate vicinity of the Mina Peggy were examined. The placer workings are in very poorly sorted river sediments ranging from rounded boulders ca. 2 metres in diameter to sand sized material. River boulders comprise very large angular to sub-rounded Tres Lagunas granite with prominent blue quartz crystals. This lithology ranges from granular to schistose in texture. Fine-grained, grey granular leuco-diorite, grey, fine-grained, feldspar-quartz-phyric dacite porphyry, white "bull" vein quartz and biotite micro-granodiorite also occur. The workings also yield rounded mineralized boulders including coarse crystalline arsenopyrite/quartz veins, vuggy vein quartz with red sphalerite, and dark banded vein quartz with arsenopyrite and chalcopyrite. The alluvial gold is rather coarse grained and waterworn and forms rounded plates. Each alluvial mine is worked by a "sociedad" of about four to eight men. Three "sociedades" were working the area and a daily yield of 10 to 15 g of gold is considered average for one mine.

Several old mine adits were examined in the area. The adits were accessible, but the faces and walls were coated in iron-oxides and dirt and little information could be obtained.

Mine dumps at the Mina Peggy yielded samples of tourmaline-cemented breccia and schist with pyrite and chalcopyrite mineralization, as well as sphalerite-veined, white altered rhyolite, and sphalerite cemented rhyolite breccia. A grey, matrix-supported intrusive breccia was also noted. Massive chalcopyrite ore with pyrite and arsenopyrite was seen and probably represents the main type of ore previously exploited in the mines.

In the vicinity of the quebrada Reote, rounded boulders of tourmaline cemented breccia, sericitized mica-schist breccia and chloritized mica-schist breccia were found on the waste dump of an abandoned alluvial gold working. The walls of the quebrada near the road comprise sericitized mica schist (sometimes with green spots of malachite), quartz-phyric rhyolite dykes (sometimes xenolith rich), and rhyolite breccia dykes.

About 300 metres north of the quebrada Reote extensive workings were examined cutting a mica schist and porphyry clast-rich, clast-supported breccia pipe. The lower (river level) adit has about 240 metres of workings and the upper (road-level) adit about 50 metres. Rocks exposed include intrusive breccia, white altered rhyolite (dyke), and mica schist. Mineralization was not obvious but some green malachite staining was visible in the upper level.

Despite previous examination and descriptions, the Mina Peggy and surrounding area are not well known or documented. This area should be examined, mapped and sampled in much more detail. The area is considered to have excellent economic potential.

2.3.3 Pilzhum (Map 2i)

The Pilzhum mine area is located about 16 km from Azogues near the Taday road at an altitude of 3400 to 3765 metres. Topography is moderately steep with open, páramo-type country. The mine and surrounding area have been examined by several individuals and organizations (INEMIN-Mision Belga, 1988; Jemielita, 1991) and is presently being examined by the Newmont mining company who hold the mining concession.

Mine dumps were examined and sampled in the Quebrada de Minas area.

Mine waste material includes grey, silicified and pyritized porphyry, vein breccias, grey, fine-grained, silicified andesite porphyry with fine-grained, disseminated and veinlet pyrite and possibly other sulphides, vuggy quartz, black siliceous vein material with fine-grained sulphides and fine to coarse plates of glassy baryte, and micro-breccias with disseminated sulphides. Coarse platy baryte vein material is common.

The Pilzhum mine area has a long history of exploitation, mostly for silver. It is likely that future production will depend upon gold values. This is an important mine and should be examined in greater detail.

3. METALLOGENESIS AND MINERAL POTENTIAL

Mineralization examined during this field survey can be classified as follows:

i) Porphyry-related polymetallic veins, intrusive breccias and disseminated mineralization.

ii) Volcanic-hosted epithermal (Au-Ag) mineralization.

iii) Shear zone-hosted quartz-tourmaline-gold veins.

iv) Quartz-tourmaline-gold pebble conglomerate palaeo-placer and oligomict placer deposits.

v) Tin and/or tungsten alluvial deposits possibly related to primary vein sources.

f) Greisen/pegmatite veins.

The porphyry related polymetallic vein-type deposits (Río Isimanchi, Sigsig-Mina Peggy, Pilzhum) are in areas of extensive, and sometimes intensive, mineralization and alteration with good potential for discovery of further mineralization. The Río Isimanchi area is handicapped by poor access and extremely rugged terrain, but it has the potential of a previously very poorly explored area with good mineral indications.

Porphyry related intrusive breccias and disseminated mineralization were examined at the Cerro de Minas near Malacatus, the Lomo del Loro (near Fierro Urcu, a known but sub-economic mineral deposit), at Sigsig-Mina Peggy and Pilzhum. Most of these areas exhibit strong polymetallic mineralization and hydrothermal alteration, and their economic potential is considered to be excellent, both within the known mineralized areas and in the vicinity.

Volcanic hosted epithermal (Au-Ag) mineralization has only been positively identified and exploited at Pilzhum, but it is a felt that there is good potential for the discovery of such deposits in the hydrothermally altered volcanic rocks around Jimbura-Amaluza, Saraguro and, doubtless, in other areas of young volcanic activity in Ecuador.

Shear zone hosted quartz-tourmaline (Au) veins have been located in basement mica schists in the Río Shincata-Río Betas area and represent a new type of mineral occurrence previously undocumented in Ecuador. This type of mineralization has contributed a significant amount to total gold produced in world terms, usually from Archaean greenstone belts, but sometimes from younger terrains. The economics of exploitation of such deposits nowadays is questionable but the potential of this mineralization should not be overlooked.

The quartz-tourmaline-gold alluvial deposits of the Río Shincata-Río Betas area are extensive and could repay investment in large scale alluvial workings. The polymict conglomerate gold placers more commonly encountered in the Cordillera Real are generally small and difficult to work by mechanical means, therefore their potential is considered low except for small scale artisanal workings.

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Geological maps (1:100000 scale): 55-Saraguro, 56-Loja, 57-Gonzanamá, 58-Las Aradas, 73 Azogues.

Topographic maps (1:50000 scale): Laguna Cox, Amaluza, Las Aradas, Yangana, Gonzanamá, Vilcabamba, Río Sabanilla, Catamayo, Loja Norte, Santiago, Las Juntas Selva Alegre, Saraguro, Nabón, Sigsig, Azogues, Guachapalá, Cañar, Cola de San Pablo.

Dr. Richard Jemielita

No. 6355

QUITO, SEPTEMBER 03, 1991

TO : ING. WILSON SANTAMARÍA

FROM : DR. RICHARD JEMIELITA

SUBJECT : Technical Report of the commission to the areas of Gima-Moriré-Espíritu Playa, San Miguel de Cuyes, Matanga, Chigüinda from July 22 to August 09, 1991

1. INTRODUCTION

1.1 Project context

The Cordillera Real Geological Project, a technical cooperation agreement between the governments of Ecuador and Great Britain and Northern Ireland, in its third phase includes the Economic Potential of the Cordillera Real subproject.

For this reason, the service commission was carried out from July 22 to August 09, with the aim of continuing the geological-mineralogical work and studies of the outcrops in the areas of interest.

1.2 Objective

To continue the geological-mineralogical research and mining evaluation work in the belt that comprises the Cordillera Real of the Andes, in order to determine its economic potential aimed at national mining development.

1.3 Assigned personnel

To carry out this work, the commission was composed of:

Dr. Richard Jemielita (ODA/BGS)

Egdo. Johnson Bolaños (INEMIN)

Sr. Manuel Célleri (INEMIN)

1.4 Transport

Jeep Land Rover license plate AT-0274 from the British Mission.

1.5 Detailed activities

Month	Day	Traverse
July	22	Quito-Cuenca (technicians and driver)
	23	Cuenca-Charqui-Río Charcay-Nabón
	24	Nabón-Quebrada Minas
	25	Quebrada Minas-Páramos de Moriré-Espíritu Playa
	26	Espíritu Playa-Peñas Blancas
	27	Peñas Blancas-San Miguel de Cuyes
	28	San Miguel de Cuyes-Altar Minas
	29	Altar Minas-Páramos de Moriré-Cuenca
	30	Cuenca-Matanga-Cuenca
	31	Cuenca-Matanga-Cuenca
August	01	Cuenca-Cuchil-Cuenca
	02	Cuenca-Río Sta. Bárbara (Morona Santiago Prov.)
	03	Río Sta. Bárbara-Chigüinda
	04	Chigüinda-Río Blanco
	05	Río Blanco-Cuenca
	06	Cuenca-Quebrada Tigre Urcu-Cuenca
	07	Cuenca-Río Sangurima-Cuenca
	08	Cuenca-Río Minas-Cuenca
	09	Cuenca-Quito

1.6 Access

Many of the study areas are partially accessible by vehicle (jeep), while in the remaining sections to reach the areas under study, it was necessary to use pack animals to carry the equipment and walk along the trails leading to those points. This is, for example, the case for reaching the Altar Minas area (Morona Santiago Province). On the eastern flanks of the Cordillera Real, where semi-jungle vegetation is present, it was necessary to hire men to clear a path using machetes and thus open a way to reach our destination, for example, the section from Chigüinda toward the headwaters of the Blanco River.

2. GEOLOGY

2.1 Río Charcay/Quebrada Minas

The quebrada Minas is a tributary of the Río Charcay and is located about 7 km east of the town of Nabón (see map 2g, Jemielita, 1991). Access is by four-wheel drive vehicle and on foot. Altitude in the area of interest is around 3170 metres and the local topography is moderately steep. Vegetation is mostly páramo with some forest.

The Quebrada Minas is about 2 to 3 metres wide and contains boulders of Tertiary volcanic and volcaniclastic rocks, and massive white vein quartz. Alluvial gold workings comprise excavations along ca. 120 metres of the west bank of the quebrada. The excavations expose a black organic top-soil underlain by fine, bedded clays (altered volcanic tuffs?) about 2 to 3 metres thick, themselves underlain by an alluvial gravel composed of rounded boulders of quartz, tourmaline, altered and fresh volcanic tuffs and lavas, porphyry and, occasionally, granular to schistose Tres Lagunas type granite and mica schist. The deposit comprises an alluvial terrace. The workings are relatively recent in origin but were not being worked when visited. Gold was panned from a yellow-coloured iron oxide-rich clay band intercalated with quartz-pebble gravel.

The auriferous gravels of the quebrada Minas contain a similar mineral suite (quartz, tourmaline, gold) to the more extensive alluvial terrace deposits in the Bestión-Río Shincata-Río Betas areas to the south (Jemielita, 1990) and were probably formed in the same manner by weathering and erosion of the granite and mica schist basement containing quartz-tourmaline-gold veins. The terraces at quebrada Minas are relatively small and could only be exploited economically by artisanal methods.

2.2 Gima-Río Moya-Río Minas (Map 3a)

The sediments of the Río Moya were examined about 6 km east-southeast of the pueblo of Gima and about 0.5 km downstream of the junction with the Río Chulo. Altitude is 2725 metres and local topography is moderately steep. Land use is mostly agricultural with scrub and páramo-type vegetation at higher altitudes. Local geology comprises bedded volcanic lavas and volcaniclastic rocks of the Tarqui Formation? Fine-grained grey mica schists of the Tres Lagunas subdivision (Loja division) are exposed in the east in the vicinity of the Río Minas.

Boulders in the Río Moya comprise rounded to sub-angular, grey, red, pink and purple coloured, feldspar-phyric porphyries and, less commonly, medium to coarse-grained granular and foliated Tres Lagunas type granite and mica schist, and fine-grained grey-black mica schist. White vein quartz pebbles are common ranging from milky to grey-glassy varieties. Some quartz has white inclusion planes and one sample had needles of black tourmaline. One sample of brown opaline silica was also noted. The Río Moya is apparently worked for alluvial gold by local people but no work was taking place at the time of the visit.

The lithologies examined in the Río Moya indicate a dominantly local volcanic source with considerable input of older granite and schist lithologies from the east. Quartz and gold are also probably derived from the older igneous and metamorphic terrain, from shear zone-hosted quartz veins. However, a possible contribution of gold from the more recent volcanic lithologies should not be overlooked, especially with the occurrence of opaline silica common in epithermal precious metals deposits. A support for the latter hypothesis is the occurrence of the gold-bearing Quebrada de Minas, a tributary of the Río Moya, which appears to drain only Tertiary volcanic rocks (Viteri and Aspden, 1989).

The Río Minas (not Quebrada de Minas mentioned above) is located about 8 km southeast of the town of Gima. Altitude in the area of interest is 3030 metres and local topography is gentle to moderately steep. Vegetation is mostly páramo. Local geology comprises fine-grained, grey-coloured mica schists (sheared granite) of the Tres Lagunas subdivision (Loja division).

Boulders in the Río Minas and its banks are dominated by white, milky, vein quartz, sometimes with tourmaline, together with fine to medium-grained mica schists, and grey feldspar-phyric porphyries and tuffs. Some blue quartz-bearing schistose Tres Lagunas-type granites were also noted.

Gold is worked from the quartz boulder-rich river terraces which are moderately extensive in the area but no miners were working at the time of the visit because of the winter season.

The presence of quartz-tourmaline pebbles associated with gold, and a mica-schist basement, indicates that the Río Minas mineralization is probably derived from shear zone-hosted quartz-tourmaline gold veins. Angular, white, vein quartz float is frequently seen on the surrounding páramo. The Río Minas deposits are similar to those of the Bestión-Río Shincata-Río Betas to the south and are probably part of the same mineralized structure (Baños front).

2.3 Gima-Moriré-Espíritu Playa (Map 3a)

A good quality road has been driven from the town of Gima east to the watershed of the Cordillera Real at Moriré. Altitudes range up to 3390 metres at Moriré. Rocks exposed in the roadcuts from Gima eastwards are mostly Tertiary to Recent volcanic and volcaniclastic rocks (Tarqui Formation?), and these are variably weathered and altered. In the east a prominent hill has been quarried for road stone. Loose blocks from these excavations comprise rhyolite breccia, porous silica-rich rock and volcanic tuffs. Haematite and manganese oxide staining is common. These lithologies could have potential for epithermal precious metals mineralization, especially in view of the occurrence of opaline silica in the Río Moya (see Río Moya section), and the auriferous Quebrada de Minas apparently draining only similar volcanic rocks. This area should be investigated further.

To the east, and at the highest altitudes on the watershed of the Cordillera Real at Moriré, the Tertiary to Recent porphyritic volcanic lithologies give way to strongly foliated and sheared, fine-grained, grey mica schists (sheared Tres Lagunas granite), generally with a steep westerly dip. The contact is unconformable. The mica schists contain numerous (<10 cm wide, occasionally ca. 1 metre wide) concordant and discordant, boudinaged quartz veins. Some of these veins carry sulphide minerals or tourmaline, but only a trace of gold was assayed in one quartz-pyrite vein-sample (Clarke, 1989).

Eastwards, and at decreasing altitudes from Moriré, the fine-grained and strongly sheared mica schists give way to a narrow band of augen schist, and then relatively undeformed Tres Lagunas-type granite with characteristic blue quartz grains. Further eastwards augen schist is again encountered followed by grey, black and purple mica schists of the Chigüinda subdivision (Loja division), which continue east to the Río Altar the most easterly location visited.

The basement metamorphic and igneous lithologies are sometimes unconformably overlain by outliers of purple-grey coloured, fine-grained, porphyritic volcanic rocks (e.g. at Hornillas), and medium to coarse-grained, weathered volcaniclastic breccias (e.g. east of Cerro Guachapalá). At the latter site bipyramidal quartz crystals form a residue on top of soils. The Cerro Pan de Azúcar and Cerro Guachapalá are probably intrusive plugs, comprising grey, medium-grained, granular, feldspar, quartz, biotite-phyric porphyry which was noted as float in the area, and associated volcanic rocks.

At the Espíritu Playa bridge angular, fractured, medium to coarse-grained (Tres Lagunas type) granite is exposed as outcrop and large river boulders. Other lithologies found as river boulders include medium-grained tonalite-granodiorite; grey and purple, feldspar-phyric volcanic porphyries; mylonitic mica schist; and some white vein quartz, sometimes containing tourmaline crystals. No alluvial gold workings were noted and local people indicated that gold was not worked at this location.

Along the track, eastwards from Espíritu Playa towards San Miguel de Cuyes, outcrop comprises medium to coarse-grained Tres Lagunas-type granite which passes eastwards into purple-grey, fine to medium-grained mica schist. Fragments and larger blocks of white, milky vein quartz are relatively common. Boulders in quebradas draining northwards into the Río Chaulli are dominated by granular and schistose varieties of Tres Lagunas-type granite with lesser quantities of fine-grained, black and white speckled granodiorite, and dark grey porphyroblastic (chiastolite?) schist. White vein quartz occurs less commonly, and one block of milky-white, glassy vein quartz with pyrite and brown iron oxides was sampled.

At one site close to a bridge crossing the Río Chaulli the remains of an old abandoned adit were visible in a vertical cliff of Tres Lagunas-type granite. The adit seems to follow a zone of fractures or veins trending approximately N18°E. The adit was inaccessible.

At the Río Moriré bridge boulders of sheared and undeformed Tres Lagunas-type granite and mica schist, some with quartz veins, were noted, together with boulders of white vein quartz.

2.4 Río Moriré (Map 3a)

The Río Moriré is a tributary of the Río Cuyes and is apparently worked for alluvial gold. The river was examined at an altitude of 2070 metres, approximately 2 km upstream of the junction with the Río Cuyes. Local topography is moderately to very steep and vegetation comprises both open agricultural meadows and thick rain forest. Access is permitted by a very poor mule track and footpath along the eastern slopes of the valley.

Local country rocks are purple-grey, fine-grained mica schists which are best observed, together with abundant white vein quartz boulders, in small quebradas. Coarse (<2 metres diameter), angular, white vein quartz is fairly common as float in fields. Country rock in the Río Moriré sample site comprises strongly foliated and lineated (rodding), fine-grained, grey mica schist (Chigüinda subdivision, Loja division). At least two super imposed foliations (deformations) are involved. Lineation trends approximately N24°E dipping SSW at 28°. A dyke of white, sugary textured, quartz-rich rock (ca. 2 metres thick) containing fine-grained disseminated and veinlet pyrite, was noted. The dyke cuts the mica schist discordantly, trending approximately N80°E and dipping ca. 65°N, parallel to a suite of small fractures which cut the schist. In addition, a zone of complex deformed and network vein quartz ca. 1-metre-wide cuts the mica schists trending ca. N50°.

River boulders comprise much sugary textured fine to medium-grained, silica-rich (intrusive?) rock with fine-grained, disseminated and veinlet pyrite; sheared and pyrite-bearing sericite schists; dark grey and silver-grey mica schists; biotite and feldspar-phyric porphyries; and white milky vein quartz, sometimes with white inclusion planes. One sample of vein quartz contained tourmaline needles. Stream sediment samples were taken but no gold was noted in pan concentrates. Local people claim that the Río Moriré is rich in gold but no miners were working at the time of the visit due to the winter season.

2.5 San Miguel de Cuyes-Río Altar (Map 3a)

The Río Altar is located to the east of San Miguel de Cuyes and is a tributary of the Río Cuyes. The Río Altar is reputed to be auriferous, particularly in the area of Altar Minas but local people claimed that the river is poor and not usually worked.

Río Altar is accessible via the town of San Miguel de Cuyes along a wide mule track (often in very poor condition). Gold is freely available for sale in the town, most originating from the Río de Cuyes (also known locally as the Río Moriré). Country rocks along the mule trail between the Río Moriré and Río Altar comprise a monotonous sequence of fine-grained grey mica schists (Chigüinda subdivision). Angular blocks of barren white vein quartz are common along the track, and in small quebradas. East of San Miguel de Cuyes on the south side of the Río Cuyes a cliff of brown iron-oxide stained, and possibly mineralized, rock is exposed. This site is very inaccessible and was not examined in detail.

Country rocks and river boulders were examined at Río Altar where the track crosses the river. Local country rock comprises grey-black mica schist (possibly graphitic) with crenulation cleavage. Folds, defined by colour and compositional banding, are mostly open with axial planar cleavage. Sense of shear is difficult to determine but is tentatively fixed as dextral with a large component of horizontal movement (based on deformation of aplite veins). Lineation associated with crenulation cleavage appears to plunge southwards at a shallow angle. Foliation trends ca. N17°E, dipping steeply west to vertical. A band (ca. 1 metre thick) of concordant, pink coloured, sericite schist with orange brown spots, reminiscent of weathering ankerite, was noted. The mica schists are cut by strongly deformed, almost ptygmatic, pink aplite veins which pinch and swell intestinally. Small, disseminated pyrite grains were noted in the aplite.

Narrow (cm-scale), white quartz veins occur as strongly deformed, concordant, and relatively undeformed discordant varieties. An orange-coloured mineral, possibly oxidized ankerite, is commonly associated with the vein quartz. The discordant quartz veins trend ca. N120°E, N70°E, with steep to vertical dips.

River boulders comprise discoid, grey-black, mica schists; silver grey and sericite schists; and some barren white vein quartz, sometimes with white inclusion planes, and/or mica schist selvages.

A stream sediment sample was taken from the side of the river, which was flooded, but the yield of heavy minerals in pan concentrate was poor, and no gold was noted.

2.6 Summary of Moriré-Espíritu Playa-Río Moriré-San Miguel de Cuyes-Río Altar area

Basement lithologies in the area are dominated by mica schists of the Chigüinda subdivision and both deformed and undeformed Tres Lagunas-type granite. The basement is intruded by small biotite-feldspar-phyric plugs and is overlain unconformably in places by younger volcanic and volcaniclastic rocks.

Mineralization is dominated by alluvial gold workings. The gold most likely, originates from shear zone-hosted quartz ± tourmaline veins which are commonly observed as angular float and rounded river boulders in the area. Other mineralization comprises disseminated and veinlet pyrite in sericite schists and granular siliceous intrusive rocks. There may be potential for disseminated sulphide and porphyry-related mineralization in the area and a proportion of the alluvial gold may originate from these sources.

2.7 Matanga (Map 3a)

The Matanga area is located 16 km south of the town of Sigsig and occupies the watershed area of the Cordillera Real. Access is by four-wheel-drive vehicle along the Sigsig-Chigüinda road. Altitudes in the area are ca. 3300 metres. Topography is moderately to very steep and vegetation is dominantly páramo. At lower altitudes thick rain forest is dominant. The Matanga area is famous for gold production and is reputed to be the highest altitude gold-producing area in Ecuador (Wolf, 1892).

Country rocks in the area are mostly fine-grained, grey mica schists of the Tres Lagunas subdivision (Loja division). These rocks contain quartz veins, often visible as angular float on the páramo, and as river boulders. The basement schists are extensively and unconformably overlain by recent (Tarqui Formation?) volcanic and volcaniclastic rocks. At one location the latter rocks were seen to be overlain by a sequence of fine-grained mudstones/siltstones and quartz-pebble gravels. The gravels are cross-bedded and generally westward-dipping. Clasts are dominantly sub-angular to sub-rounded, and moderately well sorted, white (vein-type) quartz (<10 cm diameter) with less common fragments of grey mica schist, in a fine-grained, white-yellow-red coloured clay matrix. The sequence is ca. 3 metres thick and the horizontal extent of the Formation was not determined. This formation is reminiscent of the quartz pebble terrace gravels of the Río Shincata to the south, and may be of similar age and origin.

Alluvial gold workings were examined in a small quebrada in the headwaters of the Río Ataurcu (altitude 3300 metres). The main excavations expose the banks and floor of a small quebrada. The alluvial material comprises sub-angular/rounded boulders (< 1 metre diameter) of grey mica schist and white/grey vein quartz, sometimes with mica schist inclusions, and less commonly fine-grained granodiorite.

The boulders are cemented by a ferruginous gravel and sand, which contains free gold. Pan concentrates of this material yield about ten colours of fine-grained gold per pan. The occurrence of gold in alluvium dominated by mica schist and vein quartz boulders strongly suggests that the gold originated from quartz veins (probably shear-zone-hosted type) cutting the local schist basement. On the Chigüinda road, 1 km east of the alluvial gold workings, four discordant quartz veins (<1 metre thick) were observed cutting the local grey mica schists in a parallel group. Tourmaline was not noted in any quartz veins or quartz boulders in this area.

2.8 Chigüinda road (Map 3a)

Rocks exposed in outcrop and road-cuts on the Sigsig-Chigüinda road, between the Río Blanco bridge and the town of Chigüinda, comprise variably altered and mineralized mica schists characterised by strong yellow-brown colouration. The mineralized area is exposed for ca. 2 km along the road.

Country rocks comprise strongly foliated/sheared, fine-grained, grey to black and green mica schists (Chigüinda subdivision). Foliation trends north-northeast (N36°E, N34°E) and dips variably steep to vertical. Hydrothermal alteration is ubiquitous and mostly visible as yellow-brown iron oxide staining. Sericite schists and granular (sugary-textured) quartz-rich schists are common. Mineralization comprises fracture coatings and quartz veins with sulphides. Sulphide minerals include pyrite, chalcopyrite, galena, sphalerite and molybdenite. Vein quartz textures are generally vuggy indicating epithermal-mesothermal conditions, but milky-white, massive vein quartz also occurs. Pyrite is also commonly disseminated throughout the altered schists. To the east, towards the town of Chigüinda, the altered lithologies pass into relatively fresh black graphitic schist and grey mica schist. These latter rocks contain variably deformed, milky-white quartz, veins (<15 cm wide) and narrow quartz “sweats”.

The strong foliation within the altered and unaltered mica schists suggests that these rocks have been deformed in a shear zone but the mineralization has characteristics typical of epithermal-mesothermal porphyry-related systems. Shear zone-related mineralization is known to occur throughout the region but Viteri and Aspden (1989), noted the occurrence of young porphyry intrusions in the area and the mineralization may be related to these. No porphyry intrusions were, however, noted in the road-cut.

2.9 Río Blanco-Tres Chorros (Map 3a)

The Río Blanco is a tributary of the Río Sangurima and is a substantial producer of alluvial gold. Local people claim that about 300 men work the Río Blanco, and the Río Sangurima downstream of their junction. Average production of 10 grams of gold per claim per day was estimated but greater production was not considered common. Nuggets of up to 300 grams have been found. Gold is frequently found along with subangular to rounded pebbles of magnetite-rich schist. These are known locally as "piedras tibias" because their presence is regarded as a sign that the prospect is "warm" for gold. Gold from the Río Blanco is generally coarse and forms plates and nuggets.

Two sites in the Río Blanco were examined. Upstream of the Río Blanco-Río Sangurima junction at the Chigüinda road bridge (altitude 1650 m.), local country rock comprises sheared, altered, and mineralized schists (described in the Chigüinda road section). River boulders comprise a range of lithologies including fine to medium-grained, black to light grey coloured, and often folded, mica schists, sometimes with porphyroblasts; a range of undeformed and partially deformed granitoids, including Tres Lagunas-type granite; less commonly, younger feldsparphyric porphyries are seen. White milky vein quartz boulders are common, often with mica schist inclusions. Mineralization and hydrothermal alteration are represented by boulders of yellow-brown, iron oxide-stained sericite schist; pyrite and possibly pyrrhotite in vein quartz, and pyrite veinlets seen in a granodiorite boulder. Three magnetite rich "piedras tibias" were found. Large boulders of silicified schist with relict foliation and white concordant an folded quartz veins are fairly common, and may represent silicified shear zone material. Abandoned alluvial gold workings are visible immediately upstream of this site and at various localities up-river.

The Tres Chorros area is an abandoned alluvial mine camp in the upper reaches of the Río Blanco (altitude 2035 metres). Access is by a trail of very variable quality in agricultural land, and trackless forest requiring trail cutting by machete. Outcrop and float along the access route comprises fine-grained, grey mica schists and, occasionally, yellow-brown sericite schist. White, milky vein quartz float is common.

The Río Blanco at Tres Chorros was flooded during the visit. River boulders comprise silver grey to dark grey coloured mica schists, sometimes having deformed quartz veins and pods. Some of the mica schists are sericitized and stained yellow-brown with iron oxides. Fine-grained, grey-white, feldspar-phyric porphyry is also common. One sample of garnet and blue quartz-bearing Tres Lagunas-type granite was noted. Boulders and pebbles of white, milky, vein quartz and grey, iron oxide-stained vein quartz with chloritic inclusions and mica schist wallrock, were seen. The guides claimed that this part of the Río Blanco was worked for (coarse) gold but the river was inaccessible for sampling when examined. Moss samples from the surface of a large boulder were panned and yielded a quantity of heavy minerals including fine gold.

The Río Blanco seems to be the main source of gold in the Chigüinda area and accounts for the gold workings in the Río Sangurima which are only to be found downstream of the junction of the two rivers. The presence of basement intrusive (Tres Lagunas granite), and metamorphic lithologies, with the occurrence of massive vein quartz (mesothermal type) strongly suggests that the alluvial gold originated in shear zone-hosted quartz veins (lodes). The absence of tourmaline and the presence of magnetite rich "piedras tibias" suggest however, that the nature of the source of gold may be somewhat different to that of areas to the south along the Baños front, e.g. Bestión-Río Shincata-Río Betas. The common presence of young porphyritic boulders in the Río Blanco could indicate porphyry-related mineralization as a primary gold source. Further studies will be necessary to confirm the source of the gold.

2.10 Río Sangurima-Río Santa Bárbara (Map 3a)

The area examined is in the headwaters of the Río Sangurima and in one of its tributaries the Río Santa Bárbara. The purpose of this visit was to establish the presence or absence of economic mineralization in these rivers and to determine whether the Río Santa Bárbara is in fact the Río Santa "Bárbola" mentioned in early literature as being a very rich gold producer (Navarro, 1986; Chacón, 1988).

The town of Sangurima is accessible via a rough mule-track running west from the Chigüinda road. Local topography is steep with a mixture of agricultural land and thick forest. Altitudes in the area examined ranged from 1995 metres to 2235 metres, but the area is characterized by a much greater range in altitude. Country rocks are mostly fine-grained, grey coloured mica schists, and white vein quartz is fairly common. At the Río Santa Bárbara bridge ca. 1 km W of the town of Sangurima, quartz veins (<1 metre wide) can be seen cutting the mica schist discordantly. The veins are variably deformed (boudinaged and folded). The river was flooded and inaccessible for sampling but, where visible, boulders are dominated by mica schist with some white vein quartz. Some silicified mica shist was noted in path way. The Río Santa Bárbara is steep and torrential with no alluvial terraces, and it is unlikely that it has been a substantial gold producer. Nevertheless, gold has been reported from pan concentrates (Viteri and Aspden, 1988).

The Río Sangurima was examined immediately downstream of its junction with the Río Santa Bárbara. The river was flooded, and access further upstream impractical. Local country rock comprises open folded grey mica schist with deformed, semi-concordant quartz veins (ca. 10 cm thick). River boulders are dominated by ovoid/discoid, rounded, silver-grey mica schists; some angular blocks of pink coloured mica schist; light grey semi-pelites; fine to medium-grained, grey-white granodiorite, sometimes displaying a weak fabric; silicified sericite schist, sometimes with narrow veinlets of quartz forming an intersecting network; and large and small blocks of white milky vein quartz. Stream sediment samples were taken but gold was not noted.

Local people had no knowledge of present or past alluvial, or other, gold workings in the area. It seems likely, therefore, that the headwater of the Río Sangurima and its tributary, the Río Santa Bárbara, are gold poor.

3. METALLOGENESIS AND MINERAL POTENTIAL

Mineralization examined during this field survey can be classified as follows:

i) Quartz-tourmaline-gold pebble gravel palaeo-placer- and oligomict gravel placer deposits.

ii) Shear- zone-hosted quartz (± tourmaline ± gold) veins.

iii) Pyrite veinlet/disseminated mineralization possibly related to porphyry intrusions.

iv) Pyrite-chalcopyrite-sphalerite-galena-molybdenite veinlet/disseminated mineralization in sheared mica schists-possibly porphyry-related.

Quartz-tourmaline-gold pebble gravel paleo-placer deposits occur as alluvial terraces in the Río Minas a tributary of the Río Charcay near Nabón and in the Río Minas to the east of Gima. These deposits are worked for alluvial gold and probably originated by weathering and erosion of the nearby metamorphic basement. Similar, but more extensive deposits occur to the south in the Río Shincata-Río Betas areas (Jemielita, 1990). Quartz pebble gravels also occur as bedded terraces in the Matanga area, but gold production was noted only from polymict alluvial gravels. Polymict alluvial deposits also yield gold in the Río Moriré-Río Cuyes, the Río Moya near Gima, and the Río Blanco and Río Sangurima near Chigüinda. The origin of the gold in all of these deposits is considered to be quartz (± tourmaline) veins cutting the igneous and metamorphic basement rocks in the river catchment areas. In the north, e.g. Ríos Moriré/Cuyes to Ríos Blanco/Sangurima, tourmaline is uncommon, or absent and there may be a change in the source of gold. There seems to be a general correlation between the occurrence of tourmaline in quartz veins where the veins cut Tres Lagunas granite and its sheared equivalents. A primary porphyry-related source for at least some of the gold cannot be ruled out.

Disseminated and/or veinlet pyrite is often associated with sericite schists in the Cordillera Real. In the Río Moriré boulders of such material are common and a nearby intrusive dyke contains much disseminated and veinlet pyrite. The pyritic sericite schist mineralization could be syngenetic or epigenetic but the existence of a similar mineralized minor intrusion suggests a possible connection with porphyry-type systems. This type of mineralization may be a variant of the following type:

Veinlet and disseminated pyrite are commonly associated with sericitized and silicified mica schists as well as fracture coatings, veinlets, and quartz veins containing chalcopyrite, sphalerite, galena, and molybdenite near Chigüinda. The mineralization occupies strongly foliated mica schists, possibly representing a shear zone. The vuggy nature of the mineralized veins, however, suggest a higher crustal level of epigenetic and epithermal mineralization, possibly related to a nearby porphyry intrusion, although no such intrusions were noted in the mineralized area. This mineralization should be investigated further.

From an economic standpoint the alluvial gold deposits examined are too small to warrant substantial investment and development. Shear zone hosted auriferous quartz ± tourmaline veins could provide an attractive target, but location of gold mineralized veins is difficult, especially in forested areas, and would require a considerable expenditure and exploration effort. Similar comments could be made with respect to pyritized sericite schist and intrusive dykes although there may indicate potential for larger mineralized (e.g. porphyry) systems in the vicinity. The occurrence of polymetallic (Fe, Cu, Zn, Pb, Mo), mineralization over a 2 km wide zone near Chigüinda indicates potential for substantial tonnages of near surface mineralization with relatively easy road access. The polymetallic nature of this mineralization is currently economically attractive, especially if precious metal values are obtained. This area should be investigated aggressively.

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Dr. Richard Jemielita

No. 7096

QUITO, OCTOBER, 1991

TO : ING. WILSON SANTAMARÍA

FROM : DR. RICHARD JEMIELITA and EGDO. JOHN BOLAÑOS

SUBJECT : Technical Report of the commission to the areas of Matanga; Rio Santa Barbara-Rio Ayllón; Principal; Rios San Francisco-Ishpingo-Gualaceño; Sevilla de Oro-Rios Collay-Pilares; Rio Paute-Guarumales

SUMMARY

The areas described in this report include some of the historically most productive gold producing districts in Ecuador. The abundance and range in types of mineralization described show that this region is anomalously rich and it is the opinion of the writer that this region would amply repay detailed investigation and prospecting.

1. INTRODUCTION

1.1. Project context

The Cordillera Real Geological Project of technical cooperation between the governments of Ecuador and Great Britain, in its third phase, includes the subproject Economic Potential of the Cordillera Real.

For this reason, the service commission was carried out from September 15 to October 04, 1971, with the purpose of continuing geological-mineralogical work and studies of the outcrops in the areas of interest of the subproject.

1.2 Objective

To continue the geological-mineralogical research and mining evaluation work in the strip that comprises the Cordillera Real of the Andes, in order to determine its economic potential aimed at national mining development.

1.3 Assigned personnel

To carry out this work, the commission was composed of:

Dr. Richard Jemielita (ODA/DGS)

Egdo. Johnson Bolaos (INEMIN)

Sr. Manuel Célleri (INEMIN)

1.4 Transport

Land Rover Jeep, license plate AT-0274, from the British Mission.

1.5 Detailed activities

Month	Day	Traverse
September	15	Quito-Cuenca (Driver)
	16	Quito-Cuenta (Technicians)
	17	Cuenca-Río Blanco-Páramos of Matanga-Gualaceo
	18	Gualaceo-Río Santa Bárbara
	19	Río Santa Bárbara-Qda. Obscura
	20	Qda. Obscura-Río Santa Bárbara area
	21	Río Santa Bárbara area
	22	Río Santa Bárbara-Río Ayllón
	23-24	Río Ayllón area
	25	Río Ayllón-Gualaceo
	26	Gualaceo-Principal-Río de la Burra Playa
	27	Río de la Burra Playa-Río Chorro Blanco
	28	Río Chorro Blanco-Paute
	29	Paute-Río Collay
	30	Río Collay-Collay Chico
October	01	Collay Chico- Collay Grande
	02	Collay Grande-Río San Francisco
	03	Río San Francisco-Río Gualaceño-Cuenca
	04	Cuenca-Quito

1.6 Access

Some sections of the different study areas are accessible by vehicle (jeep), such as the Rio San Francisco area. However, in most places, and especially in the high reaches of the Cordillera Real, which generally exceed 3500 meters above sea level, it is necessary to hire men and pack animals to reach the points of interest, such as the areas of the Santa Barbara, Ayllón, and Collay rivers, etc.

2. GEOLOGY

2.1 Saraguro - Río Negro (Map 4c)

The Río Negro area was visited primarily to obtain a bulk sample of Tres Lagunas granite from the type locality for U-Pb dating. The sample locality is about 18 km ENE of the town of Saraguro and is accessible via a well-defined mule track between Urdaneta and Tutupali.

Altitudes in the area range from 2480 metres to 3200 metres and the topography is generally subdued to moderately steep. Land is mostly agricultural, with páramo at higher elevations in the east.

Country rocks comprise variably weathered and altered Quaternary (Tarqui Formation?) volcanics and volcaniclastics east to the Río San Antonio. At this locality the volcanics are overlain in places by poorly bedded quartz-tourmaline pebble gravels, probably derived from the erosion of the metamorphic basement containing shear zone hosted quartz- tourmaline (+ gold?) veins. These gravels are identical in appearance to the auriferous gravels of the Río Shincata to the north. No alluvial gold workings were noted in the area but the guide claimed that gold had been won in the past. Between the Río San Antonio and the Río Negro the Quaternary volcanics can be seen resting unconformably on sheared Tres Lagunas granite and mica schist which is exposed to the east. Deformation is ubiquitous in the Tres Lagunas granite but varies from moderately deformed augen granite to very fine-grained and strongly sheared grey mica schist. Massive white metamorphic type vein quartz is common as coarse angular float in quebradas, and moderately coarse angular float in red-purple weathered schist soils and, occasionally as outcrop.

At the intersection of the Tutupali track and the Río Negro (altitude 3070 metres) about 18 km ENE of Saraguro, a bulk sample of partially weathered and iron oxide-stained, but only moderately deformed, Tres Lagunas granite was taken from a large (ca. 4 metre wide) angular block.

The occurrences of variably sheared Tres Lagunas granite with shear zone hosted (metamorphic-type) quartz veins and quartz-tourmaline pebble gravels are manifestations of Baños shearing further south than had previously been recognized. These observations suggest that auriferous alluvial and vein mineralization may also persist in this area and further work is recommended to investigate the economic potential of the area.

2.2 Páramos of Matanga-Río Minas (Map 4a)

The area examined is located in the headwaters of the Río Minas approximately 13 km south of the town of Sigsig. Altitude is approximately 3215 metres and local topography is moderately steep. Vegetation is páramo-type and access is on foot on poorly defined paths or cross-country. The weather is commonly cold, wet and misty.

An alluvial gold mine was visited which is presently being exploited by a sociedad of five men. The auriferous material comprises a moderately coarse boulder gravel of alluvial and colluvial origin. Boulders comprise mostly silver-grey mica schists, white metamorphic-type vein quartz and some altered and rotted recent volcanics. Heavy minerals are abundant in pan concentrates and the gold is golden-yellow-brown, fine-grained, irregular shaped and in equant masses. There are some plates, subrounded pellets and nuggets. Gold is often seen in quartz matrix with red hematite staining. Surfaces are medium to coarsely pitted. Red hematite-stained particles are fairly common. "Piedras tibias" of garnetiferous rock were observed. The miners claim to have found nuggets of up to 3 grammes in weight.

The composition of the alluvial/colluvial boulders reflect that of the underlying basement (Tres Lagunas subdivision; Loja division) and together with the composition and morphology of the alluvial gold, indicates an auriferous source of metamorphic-type quartz veins cutting the basement schists.

2.3 Cuchil (Map 4a)

The area of interest is located at Satunsaray, east and uphill of the town of Cuchil, about 4 km SSW of the town of Sigsig. Altitude is about 2780 metres and local topography is gentle to moderately steep. The area is mostly agricultural land.

Local geology comprises Quaternary volcanic lavas and tuffs (Tarqui Formation?). In the area examined these rocks are exposed for about 150 metres along the east side of the Sigsig-Chigüinda road. Numerous float blocks are also scattered along the road margins and in nearby fields.

The rocks comprise variously silicified, clay altered and/or brown iron-oxide-stained porphyritic rhyolite-lava flows and breccias. The breccias are sometimes polymict in composition and often have vugs containing fine-grained silica or alunite. At the north end of the roadside an exposure of a red-brown stained, vuggy, grey, silicified rhyolite porphyry breccia with disseminated pyrite forms a bed overlain by cream-white coloured rhyolite breccia. Many of the rhyolite breccias have an opaline appearance and low density reminiscent of epithermal type silicification.

The silicified and sulphide mineralized nature of these rhyolitic lithologies strongly suggest epithermal-type mineralization which is frequently associated with rhyolite volcanism and occasionally, with gold-silver and base metal mineralization. Similar rhyolitic lithologies were observed in the outcrops west of Cuchil and the entire area underlain by the Quaternary (Tarqui?) volcanics could have potential for economic epithermal mineralization.

2.4 Río Santa Bárbara - Río Ayllón (Map 4a)

The area examined in detail is located approximately 10.5 km SE of the town of Sigsig in the upper reaches of the Río Santa Bárbara and its junction with the Río Ayllón. Access is on foot along a mule trail of very variable quality south then east of the Mina Peggy. Altitudes in the study area range between 2690 metres and 2770 metres and local topography is steep. Vegetation comprises scrub and forest at lower altitudes and páramo at higher elevations. The weather is commonly cloudy, wet and cold. The area has been examined previously by geologists of the Misión Británica (Litherland et al., 1990; Clarke, 1989).

Country rocks observed along the access track are dominated by variably deformed Tres Lagunas-type granite and silver-grey coloured mica schists of the Chigüinda subdivision (Loja division). Sericitized schist with yellow-brown iron oxide staining is fairly common. In the vicinity of the junction of the Río Santa Bárbara and the Río Ayllón, country rocks comprise silver-grey and sometimes purple mica schists inter-bedded with layers of medium-grained, granular porphyroblastic schist (possibly metavolcanic tuff or greywacke). A bedding parallel foliation is common but secondary superimposed folds and crenulations are present. Fold axes plunge approximately SSE at 45° or less. The schists are affected by metre-scale open folds and primary bedding/foliation is complex in orientation. Competent beds within the schists are usually lenticular and boudinaged. Lensoid and complex-deformed tension gash quartz veins commonly intrude the basement lithologies. These veins are both concordant and discordant and are usually less than 1 metre thick but occasionally thicker.

Brittle type discordant quartz, quartz-ankerite or pure ankerite veins are found in the vicinity of the junction of the Río Ayllón and the Río Santa Bárbara. A quartz vein containing arsenopyrite, pyrite and other sulphides has been mined approximately 0.5 km downstream of the junction on the east bank of the Río Santa Bárbara. This site was previously examined by Clarke (1989) who reported gold values of 46.5 to 635 grammes/tonne for ore samples from the dump. About 1 km upstream of the junction on the east and, particularly, the west banks of the Río Ayllón hard rock workings are presently producing gold from a 0.5 metre vein which intrudes the basement schist with a trend of N67°E, dipping 68°NW. One sociedad exploiting this vein has a powerful compressor and a motor-driven ball mill in operation. Local miners claimed that other underground workings previously existed in the area and in the headwaters of the Río Ayllón. The remains of heavy machinery and steel pipe (large diameter) in this area apparently belonged to a mechanized alluvial operation.

Presently, alluvial gold washing by artisanal methods is the most commonly practiced exploitation in the area. Mining is conducted by sociedades comprising various numbers of individuals who exploit the alluvial/colluvial river banks and river bed gravels. Waste boulders are often built into accretionary walls which give a good indication of the considerable labour that has been employed in the area. Gold from the Río Ayllón and Río Santa Bárbara, when observed, was seen to be medium-grained and good quality. The gold seems to be angular in the vicinity of the junction of the rivers but forms small disc-like plates downstream in the vicinity of the Mina Peggy. Gold from the Quebrada Obscura is reputed to be very coarse.

Boulders in the Río Ayllón, upstream of its junction with the Río Santa Bárbara are dominated by sub-angular to sub-rounded, grey mica schist and more rounded psammites. Large rounded boulders of white metamorphic-type vein quartz are also fairly common. These boulders often have inclusions of mica schist. In addition, boulders of fine-grained, white volcanic rock and porphyry also occur, and medium-grained granular granodiorites are present. An angular shaped boulder of white vein-type quartz with coarse arsenopyrite was found at this locality, and similar samples were later recovered about 1.5 km upstream. Clarke (1989) reported a gold value of 5.2 g/t for a similar sample.

Alluvial miners are presently working the banks and the river bed of the Río Ayllón. One gold particle from this area was observed to be silver-coloured at one end due to amalgamation with mercury. The mercury in the river is presumably anthropomorphic in origin.

Alluvial boulders in the Río Santa Bárbara upstream of its junction with the Río Ayllón comprise light grey-white coloured mica schists and grey-green coloured, fine to medium-grained granitoids. Dark silver-grey schists are less common than in the Río Ayllón. Mineralized boulders include angular to sub-angular blocks of grey fine-grained, granular, silicified schist and sericite schist with disseminated spots of pyrite. Similar schist with a brecciated texture was noted. Boulders of silicified, quartz veined schist were observed and white metamorphic-type vein quartz, often with mica schist inclusions is fairly common

Gold was panned from coarse, iron oxide-stained alluvium on the south bank of the Río Santa Bárbara where there are moderately extensive excavations. No miners were working at the time of the visit due to the bad weather.

In the Río Santa Bárbara, about 0.5 km downstream of its junction with the Río Ayllón, river boulders include angular ta rounded pelites, semipelites granodiorites, greenschists feldspar phyric porphyries and sheared Tres Lagunas-type granite. Mineralized boulders include banded arsenopyrite and pyrite-bearing vein quartz with small red garnets arranged in parallel bands. White sericite schists and granular silicified schist, both with disseminated pyrite, are not uncommon.

In the vicinity of the junction of the Río Ayllón and Río Santa Bárbara several “piedras tibias” composed of red-green garnet-epidote rock, brown iron oxides, and brown banded magnetite schist were collected.

The occurrence of discordant, brittle fracture type quartz veins with arsenopyrite and other sulphides, and ankerite, which yield gold values in assay (Clarke, 1989), confirm that these veins are a probable source for much of the alluvial gold in the Río Ayllón and Río Santa Bárbara drainage systems. However, the presence of relatively common metamorphic-type vein quartz in outcrop and alluvium could provide an additional source of gold similar to that proposed for the Matanga area. In addition, the occurrence of sulphide (pyrite)-bearing sericite and silicified schists indicates a further type of mineralization as yet untested for gold and other potentially economic metals.

The metamorphic type quartz veins are likely associated with hydrothermal activity related to shearing along the Baños shear zone, similar to mineralization observed from the east of Saraguro to the Río Collay a distance of 120 km.

The quartz-ankerite-arsenopyrite-sulphide-gold veins may be a late expression of Baños shearing and this is supported by their banded appearance (Ribbon texture). Alternatively, these veins may be a manifestation of porphyry-related hydrothermal activity, however there is little or no physical support for the latter hypothesis.

The pyritized sericite/silicified schists and schist breccia may be syngenetic or epigenetic in origin. The source of this mineralization is unknown.

The Río Santa Bárbara-Río Ayllón area is a historical and presently gold producing area and this mineralization is possibly related to several stages or types of primary deposits. The area has high economic potential and should be investigated aggressively.

2.5 Río San Francisco (Map 4a)

The Río San Francisco lies east of the town of Gualaceo and is auriferous. Access is by good quality graded rod. The area of interest lies in the middle and upper reaches of the river at an altitude of about 3065 metres. Local topography is steep and sometimes encanyoned. Vegetation is scrub, forest and páramo. Much of the land is under agriculture. Weather is usually cold, wet and misty.

An active alluvial mine was visited in the upper reaches of the river where there is much evidence of previous workings. A sociedad of twelve men and boys work coarse alluvial gravels on the south bank of the river by artisanal methods.

Alluvial boulders comprise coarse angular to rounded blocks dominated by medium-grained, green coloured schists granodiorites, and some white sericite schists. Grey, silicified mylonites were also observed, and massive green epidotite is common. Purple-grey to white, massive, metamorphic type vein quartz, often with white inclusion planes, is quite common.

Pan concentrates are rich in heavy minerals. The gold is yellow-brown, medium-grained, irregular, flattened to equant sub-rounded plates, pellets and nuggets. The grains have fine to medium pitted surfaces, often with red-brown iron oxide coatings and are moderately waterworn.

The dominance of greenschist boulders indicates a basement source in the Alao-Paute subdivision (Alao division). Gold is most likely derived from metamorphic type quartz veins which commonly comprise boulders in the alluvium. The alluvial deposits are not large enough to warrant more mechanized production. There is potential for economic mineralization in the basement source area.

2.6 Río Ishpingo (Map 4a)

The Río Ishpingo is located east of the Río San Francisco, across the watershed of the Cordillera Real, and is accessible by the road to Indanza. The river drains eastwards towards the Oriente and is auriferous. The valley of the Ishpingo is steep sided and thickly forest, with páramo only at the highest elevations. The weather is cold, wet and misty at higher altitudes but becomes warmer and humid at lower elevations.

An alluvial mine operated by one man and two boys was visited at an altitude of ca. 2800 metres. The mine comprises coarse alluvium in the river bed consisting of rounded to angular and discoid boulders of fine-grained, silver-grey to dark grey/black mica schists, fine to medium-grained, grey-green granodiorite/diorite, grey, silicified, mica schist, and an unusual porphyritic/porphyroblastic rock with coarse sub-angular grey feldspar crystals. Greenschist boulders are less common. White metamorphic-type vein quartz boulders with white inclusion planes and mica schist inclusions are also present.

Gold is fine to coarse grained and forms angular plates and rolled/folded plates. Grains are golden yellow-brown, rarely bright golden yellow/yellow green, medium to coarse-grained, irregular subrounded, sometimes partly flattened but generally nuggets with medium to coarsely pitted surfaces and red-brown iron oxide coatings in places. The gold is a little waterworn.

The alluvial boulders are likely derived from basement of the Chigüinda subdivision (Loja division), and the gold probably originates from metamorphic-type quartz veins cutting the basement.

About 1 km east of the alluvial mine, a prominent nose of yellow-brown, iron-oxide-stained outcrop occurs for about 140 metres along the road. Outcrop comprises relatively fresh, medium-grained biotite granodiorite to the east, grading into a friable quartz-sericite-pyrite altered granodiorite to the west. A vein of massive quartz with coarse pyrite and gossan cuts the latter lithology. Further west, a relatively hard granodiorite with disseminated pyrite outcrops. The entire section is probably part of a mineralized granodiorite dyke or plug. To the east the intrusion is bounded by mica schists but further east again relatively fresh granodiorite is exposed in a landslide at the side of the road. This area should be investigated further for intrusion-related disseminated mineralization.

2.7 Río Gualaceño (Map 4a)

The Río Gualaceño is a tributary of the Río Ishpingo which drains NE from the watershed and eastern slopes of the Cordillera Real towards the Oriente. The river is auriferous and has several abandoned and active alluvial terrace workings in its lower reaches. Topography and vegetation are similar to that of the Río Ishpingo and the area examined has an altitude of 2185 metres with a warm humid climate.

Country rocks comprise grey-black mica schists of the Chigüinda subdivision (Loja division), cut occasionally by variably deformed, white, metamorphic-type quartz veins. Gold is worked from coarse alluvium which forms river terraces, often adhering to steep bedrock faces. Alluvial terrace boulders comprise rounded to sub-angular grey mica schists, grey, silicified/quartz veined schists, medium-grained granular, and porphyritic granodiorites and diorites, and metamorphic-type vein quartz. Boulders are set in a gravel and clay matrix. Silicified schists are particularly common. Heavy minerals are abundant in pan concentrates, and the gold is golden-yellow-brown, sometimes bright golden yellow, medium-grained, flattened, discoid to irregular shaped plates, some enveloping quartz inclusions. Bright golden yellow examples tend to be more equant irregular shaped nuggets and masses. Brown-red iron-oxides commonly coat surfaces which are medium-pitted. The gold is well waterworn except for the bright yellow examples. Gold is most likely derived from metamorphic-type quartz veins which cut the basement lithologies in the catchment area of the river.

2.8 Principal (Map 4a)

The area examined lies in the vicinity of the junction of the Río de la Burra Playa and the Quebrada Chorro Blanco where they join to form the Río Shio about 2 km ESE of the town of Principal. The rivers drain the western slopes of the Cordillera Real, west of the watershed. Local topography is gentle to steep with open agricultural land and some thick forest. Altitude is about 2710 metres, and the climate is warm and dry.

Local geology comprises mylonitic schists and augen schists of the Tres Lagunas and Chigüinda subdivisions (Loja division) and these rocks are well exposed in river section, especially the Río de la Burra Playa. Boulders in the latter river comprise a considerable selection including fine-grained, grey-green schists, feldspathic augen schist, sheared Tres Lagunas type granite, quartz sericite schist, silicified mica schist, diorite (including medium-grained hornblende type), metamorphic-type vein quartz/leucogranite/pegmatite, and young, coarse grained/rhyolitic volcanic breccias, sometimes containing fragments of basemen1t schists. Mineralized rocks are mostly represented by large, irregularly shaped, sub-rounded and brown iron-oxide-stained boulders of medium-grained, silicified and pyritized, grey-white, matrix supported intrusive or volcanic breccia. One boulder of silver-gray mica schist-clastic breccia with disseminated and vein pyrite was noted. Gold is reportedly won from the Río de la Burra Playa further upstream and a tributary is known as the Quebrada Minas.

Alluvial boulder lithologies noted in the Quebrada Chorro Blanco comprise a somewhat different suite including common grey-green schists, epidotite (sometimes associated with vein quartz, carbonate and sulphides), feldspathic augen schist, grey feldspar-phyric/blastic rock, diorite, purple-grey volcanic andesite, feldspar-phyric porphyry, and white altered volcanics. Mineralized lithologies are represented by rare boulders of silicified and pyritized rock (breccia?) and the previously mentioned mineralized epidotite. Massive, white, metamorphic-type vein quartz, often with green chloritic inclusions, was noted. Gold is reportedly won from alluvial workings located further upstream in the Quebrada Chorro Blanco.

An alluvial gold mine was examined on the south bank of the Río Shio immediately downstream of the junction of the Río de la Burra Playa and Quebrada Chorro Blanco. Gold is won from a pit about 3 to 4 metres deep dug into coarse river terrace alluvium of rounded boulders and gravel, partially cemented with granular pyrite which gives the alluvium its grey colour and sulphurous colour. The auriferous horizon lies below about 5 metres of this pyrite rich alluvium. Alluvial boulders are up to 1 metre in diameter and comprise the same suite of lithologies found in the alluvium of both the Río de la Burra Playa and the Quebrada Chorro Blanco. In addition, mineralized boulders include fine to medium-grained, grey-green schist wit disseminated pyrite; grey-white, silicified schist/quartzite with disseminated pyrite; dark grey, feldspar-phyric porphyry with disseminated pyrite; dark grey granular, quartz-pyrite rock with quartz veinlets; grey green mica/tremolite rock with disseminated pyrite; and grey-white, massive, metamorphic-type vein quartz with fine-grained sulphides in places. “Piedras tibias” of grey quartz-pyrite pebbles, with crystal lined vugs, are fairly common and pan concentrates from the mine are dominated by fine to medium-grained pyrite sand and gold.

Gold from the mine comprises dull, golden-yellow-brown and greenish yellow, medium to coarse grained, irregular, sub-rounded plates and nuggets, with medium to very coarsely pitted surfaces. Nuggets contain inclusions of quartz. Surfaces are commonly coated with fine-grained pyrite or iron oxides which largely accounts for the colour of the gold.

The Río Shio alluvium is the most pyrite-rich alluvium yet encountered in the Cordillera Real. The origin of this pyrite is probably the very sulphide-rich, granular, quartz-pyrite rock and breccia and "piedras tibias", and the gold may also originate from these sources. This type of sulphide mineralization is probably epithermal in character and is likely associated with Quaternary (Tarqui Formation) rhyolitic volcanics which are common in the area. The occurrence of a sulphide mineralized, mica-schist fragment breccia with abundant pyrite is not inconsistent with this hypothesis. Disseminated pyrite is also associated with the metamorphic lithologies in the area and this could provide an additional, or alternative, source for the gold. Nevertheless, the latter mineralized lithologies are less common than those mentioned above, and are a less likely gold source.

Metamorphic type vein quartz, the probable source for much of the gold found along the Baños shear zone is a further candidate for the origin of some, or all, of the Río Shio alluvial gold. At present these potential sources cannot be discriminated with confidence and further work is recommended for this strongly mineralized area.

2.9 Río Collay - Río Pilares (Map 4a)

The Río Collay is one of the most famous and historically referenced gold-producing rivers in Ecuador (Wolf, 1892; Navarro, 1986).

The Collay occupies a NNE-trending, steep sided valley of dominantly agricultural land with forest at higher altitudes and páramo at highest elevations. Altitude in the part of the river examined, around its junction with the Río Pilares, is 2750 metres. The local guide claimed that almost the entire length of the Collay and its tributary, the Pilares, is worked for alluvial gold in the summer months of November to January. He further claimed that up to 500 men work the rivers.

The Collay and the Pilares were examined in the vicinity of their junction.

Alluvial boulders in the Pilares commonly comprise black and white banded, semipelitic schist; grey-black silver coloured mica schist; silicified and quartz veined schist; massive, white, metamorphic type vein quartz, usually with mica schist inclusions; and a variety of grey, pink or white soft to hard, porphyries and volcanic rocks. Other lithologies noted include, sheared Tres Lagunas-type granite; green granular schist; silicified/chalcedonic porphyry; fine to medium-grained, grey homogeneous silicified rock; silicified volcanic and/or intrusive breccia and one boulder of quartz-ankerite vein material.

Local country rocks exposed in the river comprise grey-black, graphitic schists of the El Pan subdivision (Alao division) locally intruded by narrow (<1.5 metre wide) dykes of rhyolite porphyry, and unconformably overlain by grey-white, clay altered volcanics, themselves cut by a network of brown-black iron-oxide-stained fractures.

Gold is worked from the active river bed alluvium and alluvial terraces. At the junction of the Collay and Pilares there are extensive abandoned terrace workings. The miners claim that the gold in this locality is fine-grained but becomes finer downstream and much coarser (up to 125 g nuggets) upstream in the Pilares near the lakes at the headwaters of the river. These claims were not confirmed.

The Río Collay, immediately upstream of its junction with the Pilares, has alluvial boulders in mine waste dumps and in the river bed. Dominant lithologies include green schists; epidotites and massive, white metamorphic type vein quartz with grey/green schist inclusions. Boulders of Quaternary (Tarqui Formation) volcanic rocks are also common, and silver-grey to black graphitic schists were observed. "Piedras tibias" comprising banded and porous iron oxide gossan were not uncommon. The local miners claim that the Collay is worked for alluvial gold for about 2 km upstream of its junction with the Pilares.

The dominance of schists and metamorphic-type vein quartz in the two rivers strongly suggests that the gold originates in quartz veins cutting the metamorphic basement.

Gold seems to occur in the rivers despite variations in the basement lithologies represented by alluvial boulders. A characteristic of shear zone-hosted lodes is the occurrence of auriferous quartz veins controlled by structures regardless of the basement lithologies. Nevertheless, the occurrence of blocks of gossan, silicified porphyries and breccias, and the presence of minor rhyolite intrusions cutting the basement, permits the possibility of porphyry-related mineralization as a source or contribution to the alluvial gold budget of the rivers.

The importance of this area as an alluvial gold producer strongly suggests that exploration for the primary source of the gold could repay investment and further work in the area is strongly suggested.

2.10 Río Paute-Amaluza-Guarumales (Map 4b)

Mineralized outcrops were examined in the vicinity of the Río Paute dam and downstream towards the INECEL camp at Guarumales. Local topography is steep with open agricultural land and thick forest. Altitudes in the areas of interest range from 2150 metres to 1425 metres and the weather was clear and warm. Access is by a good quality graded road which exposes most of the sites examined.

In the immediate vicinity of the Paute dam on the southern slopes of the Río Paute valley, the granodiorite of the Amaluza pluton forms massive, grey-coloured exposures in contact with strongly fractured and brown coloured outcrop of variably altered and mineralized quartz-sericite-pyrite schist and psammitic-mica schist. Pyrite is disseminated throughout the schist, and in narrow veinlets. The mineralized section is exposed for 200 metres and more from the intrusive contact. Similarly mineralized schist occurs at the eastern contact of the Amaluza pluton and it is likely that the entire margin of the intrusion is similarly mineralized. Disseminated pyrite was also observed in the Amaluza granodiorite in a tunnel at the northern side of the Paute dam.

The existence of disseminated and veinlet sulphide mineralization associated with the Amaluza granodiorite is of great interest. Rivers draining the western margins of the pluton are anomalous in zinc, lead and molybdenum (Bristow et al., 1975) and large potential tonnages of mineralized rock could exist within the intrusion and its mineralized margins. This area should be examined in further detail.

Between the Amaluza pluton east contact and Guarumales outcrops of schists the Alao-Paute and Upano subdivisions outcrop, sometimes containing massive white metamorphic-type quartz as variably deformed veins.

A few hundred metres west of Guarumales a roadcut and landslide expose strongly brown iron oxide-stained outcrop comprising black mica schist with white quartz veins or segregations, and some pyrrhotite, pyrite, chalcopyrite and sphalerite as fine crystals. The mineralized zone appears to be relatively narrow (tens of metres) and continuous uphill. Blocks of banded (millimetre-scale), and deformed quartz-sericite schist and massive white vein quartz, both hosting pyrite, occur in this area.

On the east bank of the Río Paute, immediately downstream of the Guarumales bridge, about 60 metres of strongly mineralized schists and massive polymetallic sulphides are exposed as strongly brown iron-oxide-stained rock in a roadcut. The mineralized rock is dominated by white and green mica schists with more or less fine to medium-grained disseminated pyrite. Massive sulphide beds occur within the schists.

The sulphide beds range from a one-metre-thick bed of massive pyrite to narrower (ca. 10 cm thick) beds of finer grained, granular, bedded and folded, polymetallic sulphides i.e. pyrite, chalcopyrite, galena. A quartz-mica rich pod, with coarse chalcopyrite, sphalerite and other sulphides, was also sampled. The local country rocks comprise black, grey and green mica schists of the Upano subdivision (Litherland et al., 1990).

On the north bank of the Río Paute, opposite the Guarumales massive sulphide outcrop, more brown iron-oxide-stained rock is visible in prominent outcrops. In addition, on the road leading to the electrical transformer station, outcrops of brown iron oxide stained and pyrite mineralized schists are exposed in places.

The massive sulphide mineralization at Guarumales is probably of volcanogenic origin and its occurrence, together with the numerous sulphide mineralized schists outcrops in the near vicinity, is a strong indication of the economic potential of the area. This area should be examined aggressively, together with other parts of the Upano subdivision, and the Alao-Paute subdivision where similar mineralization has been described previously (Jemielita, 1991a).

3. METALLOGENESIS AND MINERAL POTENTIAL

Mineralization examined during this field survey can be classified as follows:

i) Shear zone-hosted quartz ± tourmaline ± gold veins in schists.

ii) Brittle type, discordant quartz ± ankerite, arsenopyrite, pyrite, other sulphides, ± gold vein mostly in schists

iii) Alluvial riverbed and alluvial terrace gold placers, including quartz-tourmaline pebble gravels.

iv) (Volcanogenic?) Massive polymetallic sulphides and associated disseminated sulphides in schists.

v) Disseminated and veinlet sulphides in granodiorites and their host rocks.

vi) Disseminated sulphides in rhyolite (and chalcedonic silica?) breccias.

vii) Disseminated sulphides in quartz-sericite schists and schist breccias.

viii) Disseminated sulphides in silicified volcanic or intrusive breccias.

ix) Massive pyrite-silica vein material as “Piedtas Tibias”.

Shear zone hosted quartz veins were observed within sheared Tres Lagunas-type granite, and associated mica schists, in the vicinity of the Río Negro to the east of Saraguro. This type of mineralization is similar to that observed to the north-east in the Río Shincata area (Jemielita, 1991b) and which is thought to be the primary source of alluvial gold mineralization in the area. In the Río Negro area, there is much angular vein type quartz float associated with altered and weathered Tres Lagunas granite and schist. In addition, there are quartz-tourmaline pebble gravels similar to the auriferous placer terraces of the Río Shincata and Río Betas. No alluvial gold workings were observed in the Río Negro area but the guide claimed that gold had been worked in the past. The similarity between the geology and mineralization in the Río Negro area with that occurring in the north-east along the Baños shear zone indicates potential for alluvial and lode gold in the Río Negro area. Furthermore, the observations in the Río Negro area indicate that Baños shearing and associated mineralization continue further south than previously realized.

Brittle-type, discordant quartz, ankerite, and quartz-ankerite veins, often with arsenopyrite, and other sulphides (pyrite, chalcopyrite), as well as gold, were observed in the Río Ayllón and Río Santa Bárbara areas (Clarke, 1989; Jemielita, 1991b; this report). These veins are generally narrow (ca. 0.5 metres) and discordant, cutting the country rock schist lithologies. In the vicinity of the Mina Peggy, near Sigsig, polymetallic mineralization rich in arsenopyrite is associated spatially with young rhyolite porphyry intrusions. It is possible that the quartz-ankerite arsenopyrite-sulphide veins are also related to porphyry intrusions but such a link has not been unequivocally established. The banded (deformed) textures in these veins tend to support a shear zone connection.

Alluvial riverbed and terrace gravel gold were observed in the Río Minas (Matanga), Río Ayllón-Río Santa Bárbara, Río Shio-Río de la Burra Playa (Principal), Río San Francisco, Río Ishpingo, Río Gualaceño and Río Collay-Río Pilares. The source of this alluvial gold has not been firmly established but the occurrence of metamorphic-type (shear zone-hosted) vein quartz in all of the rivers suggests that these types of veins may constitute the primary source of gold. Nevertheless, auriferous quartz-ankerite-arsenopyrite-sulphide veins in the Río Ayllón-Río Santa Bárbara may comprise an additional or dominant source for alluvial gold in these rivers. The abundance of alluvial pyrite and pyrite mineralized breccias and porphyries, associated with the gold placers of the Río Shio may indicate a younger porphyry-related, or epithermal, source for primary gold mineralization in the Principal area. The morphology of the alluvial gold from all of the areas described is quite variable in terms of grain size and shape, and sometimes colour, but the significance of these differences is not presently known. It is proposed to examine the alluvial gold and associated heavy minerals in more detail in the near future.

Massive, bedded polymetallic sulphides of possible volcanogenic origin were observed in the Guarumales area of the Río Paute and comprise a significant target for further exploration. These deposits occur within well foliated mica-schists, of probable volcanic and sedimentary origin. Similar style mineralization comprises huge economic deposits in other parts of the world. Massive sulphide mineralization has been previously described in the Cordillera Real (Jemielita, 1991a).

Disseminated and veinlet pyrite has been observed in the margins and altered schist wallrocks of the Amaluza pluton in the Río Paute area. This mineralization is potentially significant because of the known occurrence of anomalous zinc, lead and molybdenum in stream sediments in the area and the large potential tonnages of such mineralization. Another more intensely mineralized granodiorite was observed in the Río Ishpingo valley and it is possible that a suite of similarly mineralized intrusions exists in the Cordillera Real (e.g. see geological maps in Litherland et al., 1990).

Disseminated pyrite occurs in rhyolite breccias and possible chalcedonic/opaline silica breccias in the Cuchil area near Sigsig. The country rocks are Quaternary rhyolitic volcanics, probably of the Tarqui Formation, and this mineralization may represent epithermal hydrothermal activity with potential for bulk tonnage disseminated precious metals. The entire Tarqui Formation and, indeed, the older Saraguro Formation volcanics are considered prospective for this type of target (Jemielita, 1991b, c).

Disseminated pyrite in silicified, matrix-supported breccias and porphyries were observed in the Principal area, specifically in the Río Shio and Río de la Burra Playa. This type of mineralization is probably associated with epithermal activity within the Tarqui Formation volcanics and may be part of a similar system of mineralization as that represented by the Cuchil breccias. Also common in the Río Shio are rounded pebbles of pyrite-silica vein material as well as abundant pyrite sand. This material is also considered to be of epithermal origin and, together with the occurrence of coarse gold in the area, indicates possible potential for epithermal precious metals deposits.

Finally, in the upper reaches of the Río Santa Bárbara, numerous river boulders of quartz-sericite schist, sometimes with a deformed breccia texture, carry fine-grained disseminated and veinlet pyrite. The origin of this mineralization is not known and it may represent altered selvages to mineralized quartz veins or syngenetic mineralization. The common occurrence of these boulders indicates a significant source and this should be investigated further.

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No. 7662

QUITO, DECEMBER 04, 1991

TO : ING. WILSON SANTAMARÍA

FROM : DR. RICHARD JEMIELITA and EGDO. JOHN BOLAÑOS

SUBJECT : Technical Report of the commission carried out to: Macas-Rio Upano; Osogochi-Cerro Pucurcu Grande-Cerro Tintillay-Cerro Soroche; Laguna Atillo-Laguna Negra (Guamote-Macas road), from November 04 to 22, 1991

SUMMARY

This field survey has yielded a range of types of mineralization all of which have significant economic potential. The enormous size of some of these mineralized zones is very encouraging and it is felt that all of these areas would repay detailed examination.

1. INTRODUCTION

1.1 Project context

The Cordillera Real Geological Project, a technical cooperation agreement between the governments of Ecuador and Great Britain, in its third phase includes the Economic Potential of the Cordillera Real subproject. For this reason, the service commission was carried out from November 04 to 22, 1991, with the aim of continuing geological-mineralogical work and studies of outcrops in the areas of interest of the subproject.

1.2 Objective

To continue geo-mineralogical research and mining evaluation work in the strip comprising the Cordillera Real of the Andes, in order to determine its future economic potential aimed at national mining development.

1.3 Assigned personnel

To carry out this work, the commission was composed of:

Dr. Richard Jemielita (ODA/BGS)

Egdo. Johnson Bolaños (CODIGEM)

Sr. César Vinueza (CODIGEM)

1.4 Transport

Jeep Land Rover, license plate AT-0274 from the British Mission.

1.5 Detailed activities

Month	Day	Traverse
	03	Quito-Macas (Driver)
	04	Quito-Macas (Technicians)
	05	Macas-9 de Octubre-Río Abanico
	06-07	Área del Río Abanico
	08	Río Abanico-Río Upano
	09	Río Upano-9 de Octubre-Macas-Gualaceo
	10	Gualaceo-Paute-Sevilla de Oro-Santa Teresita-Río Collay
	11	Río Collay-Santa Teresita-Paute-Gualaceo-Alausí
November	12	Alausí-Guasuntos-Totoras-Osogochi-Laguna Cubillín
	13	Laguna Cubillín-Cerro Pucurcu Grande-Laguna Cubillín
	14	Laguna Cubillín-Cerro Tintillay-Laguna Cubillín
	15	Laguna Cubillín-Cerro Soroche
	16	Cerro Soroche-Osogochi
	17	Osogochi-Atillo
	18-20	Área del Río Atillo
	21	Área del Río Atillo-Riobamba
	22	Riobamba-Quito

1.6 Access

Some of the study sections are accessible by vehicle (British Mission Land Rover), such as the Guasuntos-Osogochi section, where four-wheel drive had to be used, but in high sections of the Cordillera that generally exceed 3500 meters above sea level, it is necessary to walk and use pack animals to reach the points of interest and fulfill the proposed objective, such as Cerro Soroche (approx. 4730 meters above sea level).

2. GEOLOGY

2.1 Macas-Río Abanico-Río Upano (Map 5a)

The area examined is located in the vicinity of the junction of the Río Abanico and Río Upano between 12 and 22 km WNW of the town of Macas. Both of these rivers originate in the highest elevations of the Cordillera Real and drain the eastern slopes. Both rivers are auriferous. Local topography is moderate to steep with open agricultural land and thick forest. Altitudes in the areas examined, mostly along the incomplete Guamote-Macas road, range from 1565 metres to 1925 metres. The area is accessible by four-wheel drive vehicle and on foot. Climate is warm and humid.

Local geology comprises an Andean-trending metavolcanic and metasedimentary sequence of graphitic (Napo Formation) and mica schists and quartzites of the Upano subdivision (Salado division; Litherland et al., 1990). These lithologies are intruded by a composite (Colimbo) intrusion of dioritic to granodiorite composition.

Indications of mineralization are common along the Guamote-Macas road and comprise strong to moderately (brown-yellow) iron-oxide-stained outcrops between the Río Abanico-Río Colimbo junction in the east and the Río Upano-Río Cugusha junction in the west (Macas and Zuñac, 1:50000 Censal maps), a distance of about 16 km.

About 0.5 km west of the Río Abanico-Río Cugusha junction is a prominent iron-oxide-stained outcrop composed of black carbonaceous/graphitic schists, probably deformed examples of the Napo Formation. The schists are well bedded and some display a beautiful (centimetre scale) banding of alternating fine-grained black schist and lighter grey coloured quartzite. The schists are moderately well foliated and deformed by open (metre scale) folds. Crenulation cleavage and associated lineation is sometimes visible. The strike and dip of the foliation and bedding is complex due to folding but a generally east-west strike predominates with steep to horizontal dips.

Mineralization comprises deformed, massive to vuggy, white quartz veins with coarse pyrite and, sometimes, a white-pink-green coloured platy mineral, possibly alunite. A black powdery mineral, probably a manganese oxide, was also noted. Pyrrhotite, possibly pyrite and chalcopyrite comprise coarse blebs and finer disseminated crystals throughout the matrix of the schist and quartzite. Elongate masses of sulphide occur parallel to relict sedimentary bedding. Alteration mostly comprises silicification. On the Macas geological map (1:100000 scale) this site is credited with iron and molybdenum mineralization, but the latter metal was not noted during the present survey.

The nearby Río Colimbo contains abundant xenolithic, white coloured, biotite-hornblende granodiorite as well as graphitic schist and silicified and banded schist/meta-sediment. It is likely that this area is close to the contact with the Colimbo intrusion, and mineralization is probably related to this intrusion which is also mineralized (see below). Hydrothermal mineralization in carbonaceous/graphitic lithologies is of great interest due to the occurrence of economic epithermal gold mineralization in such lithologies e.g. at the Carlin gold mine in Nevada, U.S.A.

Further to the northwest and west along the Guamote-Macas road, outcrops of mica schist and psammites contain fine to medium-grained, disseminated sulphides (pyrite, pyrrhotite, chalcopyrite) and veinlets. In addition, massive, deformed, white quartz veins (metamorphic-type) and white to black, fine-grained, sugary textured to chalcedonic, sulphide rich quartz veins (epithermal type) cut these lithologies in places. Mineralization and alteration (sericitization and silicification) within the schists are variable in intensity. The strongest mineralization is exposed as a 200-metre-long outcrop of strongly iron-oxide-stained schists about 3 km NW of the Río Salado Grande.

River boulders in the Río Salado Chico comprise very large to small sub-angular to sub-rounded, leucocratic, medium-grained, biotite-hornblende granodiorite, often with angular to rounded xenoliths of fine to medium-grained diorite. The diorite also occurs as less common boulders. Dark grey coloured, indurated mica schists, sometimes with metamorphic type quartz veins, also occur. Many boulders are brown coloured due to iron oxide staining, and have disseminated pyrite. Greenschist and graphitic schist are also present but not common. One greenschist boulder was observed to be cut by a hornblende pegmatite and had disseminated chalcopyrite.

The Río Salado Grande is larger than de Chico but the river boulders are smaller in size. Lithologies include silver-grey-black mica schists, usually strongly deformed. A grey, medium-grained, biotite-hornblende granodiorite is common and often contains disseminated pyrite and chalcopyrite. Sulphides are also disseminated in fine-grained, grey, indurated hornfels, metamorphic type vein quartz, and white, banded schist. Other lithologies include a red-green mica-epidote rock; green-white, banded amphibolite, and pink-beige fine-grained aplite.

The Río Salado Grande generally has a higher proportion of schists and less granodiorite than the Salado Chico. Both rivers contain abundant sulphide mineralized lithologies. Limonitic springs occur in the vicinity. Neither of these rivers is worked for gold.

Further west, river boulders in the Río Cugusha are dominated by silver-grey, and sometimes black mica schists with narrow (centimetre scale) metamorphic-type quartz veins. Less common lithologies include fine-grained, grey, porphyritic volcanics; fine-grained, beige-coloured, granular, micaceous monzodiorite; medium-grained, grey xenolithic monzonite/monzodiorite; white, medium-grained, granular, xenolithic, biotite granodiorite; and massive, white, metamorphic type vein quartz, often with mica schist inclusions. A boulder of maroon-coloured volcanic breccia or agglomerate was observed, together with a boulder of mica schist-xenolithic granodiorite intrusion breccia. Maroon coloured andesitic boulders are not uncommon. Mineralized samples are uncommon but one boulder of fine-grained, granular, silica-pyrite rock (mineralized intrusive?) was noted.

Alluvial gold is worked in the Río Upano. The alluvial mines were not being operated and were not visited, but gold was observed belonging to miners in the nearby town of 9 de Octubre. The gold is a deep yellow colour and of good quality. It is typically fine-grained and comprises small circular and irregular, but rounded, flattened plates with fine to coarse pitted surfaces.

Alluvial gold is also reputed to be mined from the nearby Río Abanico.

To summarise, the area comprises a sequence of variably sulphide mineralized, hydrothermally altered and weathered metasediments and meta-volcanics, intruded by a generally fresh and variably sulphide mineralized composite diorite-granodiorite pluton (Colimbo intrusion). Massive, but generally small, deformed metamorphic-type quartz veins cut the schists in places, but epithermal-type quartz veins, often with associated sulphides, are more common.

The widespread, and often strong, hydrothermal alteration and mineralization is attributed to the Colimbo intrusion. This intrusion is not porphyritic but it is mineralized and may have mineralized its country rock margins by evolving magmatic-hydrothermal fluids, or by providing a thermal source for convecting groundwaters to circulate. This survey, together with previous work in the area, indicates the presence of iron, copper, molybdenum and gold mineralization and it is possible that the Colimbo pluton and its mineralized margins could have significant economic potential.

2.2 Osogochi-Cerro Soroche area (Map 5b)

This area is located about 45 km SSE of the town of Guamote on the watershed of the Cordillera Real. Altitudes in the area examined range from about 3800 metres to 4730 m and the topography varies from gentle to alpine. Vegetation is páramo and the climate is cold and wet. The area is accessible by four-wheel drive vehicle along gravel road from Palmira or Cumballa (see Zula valley) via Totoras and Osogochi, then by mule or on foot.

Local geology is dominated by recent lavas and volcanoclastics rocks to the west which unconformably overly extensively, and often intensively, quartz-veined basement black schists and quartzites of the Punín subdivision (Guamote division; Litherland et al., 1990) and partially overlap greenschists of the Alao-Paute subdivision (Alao division) to the east. The latter rocks comprise some of the highest peaks on the watershed, including Cerro Soroche (4730 m) the highest schist peak of the Cordillera Real.

The area surveyed is located south at Laguna Cubillín (Totoras 1:50000 sheet). A prominent rocky mountain with red coloured talus slopes named Cerro Pucurcu Grande (Quechua equivalent of Cerro Colorado or Red Mountain) dominates the area west of Cerro Soroche. The red colour is due to iron-oxide staining of the disseminated pyrite-bearing, feldspar-phyric porphyry of which the mountain is composed. In detail, the rocks are medium-grained, grey-white, variably altered, and pyrite mineralized feldspar porphyries. The feldspars are altered and epidote is often present. Samples vary in colour and intensity of alteration. Pink feldspars are sometimes present and purple coloured altered porphyry was noted. Some samples have a medium-grained breccia texture with altered and pyritized breccia clasts. Purple-green fine-grained, porphyritic dacite with little or no pyrite was also noted.

Away from the most mineralized outcrop (about 3 km^2) of Cerro Pucurcu Grande the country rocks comprise medium-grained, grey porphyritic andesites, sometimes with epidote (propylitic) alteration. This lithology contains small areas of more intense alteration and mineralization in places.

Other areas of relatively extensive and intensive hydrothermal alteration and mineralization include the northwest slopes of Cerro Tintillay. A narrow valley here contains yellow-brown coloured scree comprising white-grey, altered and silicified andesite porphyry and breccia with fine to medium-grained disseminated pyrite and rarer chalcopyrite. The quebrada downhill from this site contains an alluvial/colluvial coarse sediment of altered and mineralized porphyry in a clay matrix. This material is grey in colour but where oxidized it is stained brown with iron oxides. Pan concentrates of this material comprise almost pure pyrite.

On the eastern slopes of the mountain (4060 m) to the west of Laguna Verde Cocha, a sample of iron oxide-stained, silicified and pyritized porphyry was examined. This sample appears to have originated from outcrops uphill on the mountain (4060 m). The nearby quebrada Yuracyacu exposes much brown iron oxide-stained outcrop. A sizeable landslide immediately north of the lower reaches of this quebrada exposes strongly brown iron oxide-stained outcrop and talus of grey-white porphyry breccia composed of fine to medium grained porphyritic volcanic rock with abundant fine-grained disseminated and veinlet pyrite.

Most of the lithologies described above are probably lava flows and volcaniclastic rocks but, in the absence of detailed mapping some exposures may be intrusives or intrusive breccias. Cerro Pucurcu Grande is considered particularly important because of the large area of mineralized porphyry. In addition, a Cerro Pucurcu Chico is marked on the Huangra (1:50000 scale) topographic map about 3 km SSW of Cerro Pucurcu Grande, and is probably of similar composition. Economic potential is suggested by the existence of a quebrada de Minas on the eastern side of Cerro Pucurcu Chico. Local guides suggest that this quebrada is auriferous. It is likely that the extensive hydrothermal alteration and mineralization associated with these porphyritic lithologies is related to high level porphyry intrusions, an important potential source of a range of economic mineral deposit types. Further investigations are strongly recommended in the area.

The original purpose in visiting this area was to examine Cerro Sorochi (or Soroche) for economic mineralization. Soroche is a commonly used term to denote sulphides (more especially silver-bearing galena) but can also mean altitude sickness (Cerro Soroche is 4730 metres at the summit). The mountain was confirmed to be composed of green schists and greenstones of the Alao-Paute subdivision by examining angular boulders at the foot of the northwestern slopes around Laguna Verde Cocha Chica. These rocks were cut in places by metamorphic-type quartz and calcite veins, and fine to coarse disseminated pyrite is sometimes present. Chlorite and epidote are ubiquitous. No strong mineralization was noted during this short visit and more trough exploration of the mountain would require a considerable expedition. Cerro Soroche is one of the non-volcanic peaks in Ecuador with a permanent ice cap (Hastenrath, 1981). The origin of the name Soroche remains unconfirmed but the presence of volcanogenic massive sulphide (VMS) type mineralization in other areas of the Alao-Paute subdivision, as well as similar lithologies in the Upano subdivision, would encourage investigation of this area.

2.3 Atillo-Laguna Negra

The Atillo-Laguna Negra area is located about 35 km SE of the town of Gualaceo and is accessible by 4-wheel drive vehicle along the Guamote-Macas road. Altitudes in the area examined range from 3300 to 3600 metres. Topography is gentle to very steep and vegetation is mostly páramo. Cattle grazing is practiced in the wide, U-shaped glacial valley of the Río Atillo.

Local geology is dominated by recent volcanic and volcaniclastic rocks and, possibly porphyritic intursions, which cover much of the area west of Laguna Atillo. In the vicinity of Laguna Atillo fossil fish have been reported (Patterson, 1990) from fine-grained lacustrine sediments. The volcanic and sedimentary lithologies unconformably overlie green-schists and greenstones of the Alao-Paute subdivision which are exposed east of Laguna Atillo, especially along the Guamote-Macas road.

In the vicinity of the town of Atillo roadcuts expose several sizeable outcrops of yellow-brown, iron oxide-stained and hydrothermally altered and mineralized porphyries. In detail, the porphyries are fine to medium-grained, grey, feldspar-phyric dacites. Where fresh, the feldspars exhibit albite twinning. More commonly the porphyry is strongly kaolinized and/or sericitized and silicified in places. Fine-grained pyrite commonly occurs disseminated and in fractures or veinlets and native sulphur has been reported from this locality (Litherland et al., 1990). The mineralized porphyry sometimes has a brecciated appearance and is cut in places by a narrow (centimetre scale) network of fine-grained, grey, granular intrusive veins or dykes. The porphyry is mapped (Alausí 1:100000 geological map), as part of the Tarqui Formation of volcanic and volcaniclastic rocks, but may be intrusive. It is most likely that the hydrothermal activity is epithermal mineralization related to porphyry intrusion(s), and this area should be examined further for economic potential, especially for precious metals.

To the east of the town of Atillo on the north shore of Laguna Atillo a roadcut exposes a beautifully bedded and banded sequence of lacustrine sandstones (up to 1 metre thick) and fine-grained (possibly bituminous) mudstones. These lithologies are commonly brown-yellow stained with iron oxides. These sediments may have potential as a source of diatomite.

East of Laguna Cuya towards Laguna Negra and across the watershed to the headwaters of the Río Upano, greenschists, greenstones and grey-schists of the Alao-Paute subdivision (Alao division) are extensively exposed, especially in fresh roadcuts along recently excavated section of the (presently incomplete) Guamote-Macas road.

Along the northern shore of Laguna Negra greenschists and greenstones comprise a classical exposure of strongly sheared rocks. The exposure is characterized by competent massive and slightly boudinaged greenstones (up to several metres wide) with intervening bands of strongly sheared and foliated greenschists. The greenschists generally have fabric-parallel, massive white, metamorphic-type quartz veins (several cm scale) and similar fine-grained, granular calcite veins. In contrast, the more massive greenstones display tension veins (up to 10 cm thick) sometimes in en-echelon groups normal to the plane of shearing (ca. N5°E dip 76°W), and composed of massive white metamorphic-type vein quartz, often with associated grey-white ankerite, pink carbonate, and/or coarse green crystals of chlorite. These veins often have grey-pink alteration selvages, probably due to carbonatization. The veins, greenschists and greenstones all carry more or less pyrite and some chalcopyrite was noted. This is a classic example of a mineralized shear zone and is it least 500 metres wide at this locality. Similarly mineralized shear zones commonly host significant gold mineralization in Archaean and younger greenstone terranes; therefore, this example should be investigated aggressively for economic potential.

To the east of Laguna Negra the greenschists and greenstones give way to grey and black, sometimes graphitic, mica schists with foliation trending ca. N173°E, dipping ca. 80°W. In places these lithologies are cut by narrow (1 to 2 cm scale) quartz-calcite-pyrite-chalcopyrite veins. The veins are both concordant and discordant and sometimes boudinaged. Veins up to 10 cm thick are quite common. To the west of Río Galgalan, a several metre thick zone of massive, white, deformed quartz veins is associated with coarse disseminated pyrite mineralization in the greenschists vein selvages. Pink carbonate alteration is strong at this locality and chlorite is present in places as a vein mineral. Ankerite was also tentatively identified as a vein mineral.

The entire exposure of green and grey schists and rocks east of Laguna Negra exhibits alternating zones of more massive and more schistose (sheared/mylonitized) lithologies. Hydrothermal mineralization represented by quartz, calcite, chlorite, ankerite, pyrite, chalcopyrite in veins and alteration selvages is common and probably the best example of shear zone related mineralization yet seen in the Cordillera Real. This type of mineralization is thought to be the source of much of the alluvial gold found in rivers draining the Cordillera Real and, as mentioned above, there is considerable economic potential for primary (hard rock) mineralization of this type.

2.4 Río Collay - Río Pilares (Map 4a)

The Río Collay-Río Pilares area was revisited to examine gold and to take mineral samples from alluvial mines in the area. For geological and geographical background information see Jemielita and Bolaños (1991).

The alluvial mines were in operation in the Río Pilares a few hundred metres upstream of its junction with the Quebrada Huagrarumi. The upstream mine, employing about twelve men, was not visited. The downstream mine (Sociedad Cari Collay) employs thirty men who had excavated a five-metre dep pit in the middle of the river. The pit exposed a bedrock of yellow-brown coloured, clay-altered volcanic rock and auriferous alluvium which is described in detail in Jemielita and Bolaños (op. cit.).

Gold from the mine is moderately coarse (up to 0.5 g chispas claimed by the miners) and a deep golden yellow in colour. The individual grains are typically thin to thick, flattened, semi-discoid plates, rolled elongate, irregular grains and cylinders, and extremely irregular masses. Dark, brown iron oxides sometimes coat grain surfaces which are finely to very coarsely pitted. Associated heavy minerals appear to be rich in pyrite. The production from half a day of work amounted to only 5.3 grammes, a poor yield for thirty men.

Another pit was being prepared by a sociedad of twelve men at the junction of the Río Pilares and the Quebrada Huagrarumi where they join to form the Río Collay. No gold or heavy mineral samples were available for examination but many angular to sub-angular blocks of porous, silicified, grey-beige-brown coloured porphyry-breccia with very fine-grained pyrite in the unoxidized (grey) areas where observed. These samples are very common and represent an acid leached epithermal mineralized porphyry-breccia. Lithologies displaying this type of composition and mineralization have very good precious metals potential.

A few hundred metres downstream of the Río Pilares-Quebrada Huagrarumi another pit was excavated by twelve men in the riverbed. Bedrock exposed in this pit comprised grey schists, and much angular, brown iron oxide-stained, grey-yellow, pyritised mica schist occurs in this vicinity, probably derived from a mineralized schist exposure on the actively eroding side of the river. This strongly pyritized schist lithology could have potential as a source of gold and other metals.

In summary, the origin of much of the alluvial gold in the Río Collay-Río Pilares area is attributed to metamorphic type quartz veins in the extensive drainage catchment area. Nevertheless, the occurrence of volcanic rocks and rhyolite intrusions as previously reported (Jemielita and Bolaños, 1991), together with the discovery of acid leached, pyritized porphyry breccia during this visit, is strong evidence in favour of the occurrence of epithermal-type mineralization in the area possibly contributing to the gold budget of the river.

3 METALLOGENESIS AND MINERAL POTENTIAL

Mineralization examined during this field survey can be classified as follows:

i) Alluvial riverbed and alluvial terrane gold placers.

ii) Shear zone-hosted quartz ± ankerite ± calcite ± chlorite ± pyrite ± chalcopyrite ± gold veins and associated alteration selvages in schists.

iii) Disseminated pyrite ± chalcopyrite in schists (intrusive-related).

iv) Brittle-type quartz-pyrite veins and associated disseminated and fracture coating pyrite in graphitic schists, mica schists and semi-pelites.

v) Disseminated pyrite ± chalcopyrite in diorite and granodiorite.

vi) Disseminated pyrite in dacite porphyry volcanic and/or intrusive rocks and breccias.

vii) Acid leached, porous silica, porphyry breccia with disseminated pyrite.

Alluvial riverbed and terrace gold placers were encountered in the lower reaches of the Río Upano immediately upstream of its junction with the Río Abanico. The source of this gold is not known but may be related to metamorphic-type quartz lodes cutting the schist basement in the catchment area. This is supported by the common occurrence of massive metamorphic-type vein quartz as river boulders in rivers and quebradas draining into the Río Upano, as well as the relatively common occurrence of such veins in outcrop in exposures along the Río Upano section of the Guamote-Macas road. Nevertheless, extensive, and often intensive, sulphide mineralization associated with the Colimbo granodiorite intrusion and its aureole may also contribute gold to the rivers. The Río Abanico is also known to be auriferous but was not examined.

The Río Collay-Río Pilares are famous as past and present gold producers (Navarro 1986; Wolf, 1892). Gold is likely derived from metamorphic-type quartz veins cutting the extensive schist basement in the catchment area. Nevertheless, the occurrence of volcanic and intrusive lithologies, together with indications of epithermal-type mineralization could provide an additional, if not an alternative, source for the gold.

Shear zone-hosted quartz ± ankerite ± calcite ± chlorite ± pyrite ± chalcopyrite (± gold?) veins were encountered in exposed Alao-Paute subdivision schists and rocks east of Laguna Atillo and in the upper reaches of the Río Upano along the Guamote-Macas road. These are the best exposures of such mineralization seen, to date, in the Cordillera Real and are probably representative of the type of primary mineralization responsible for much of the alluvial gold in rivers draining the Cordillera. Such mineralization constitutes an important source of gold and silver in other parts of the world, notably Canada, Australia, Brazil and South Africa, and could have economic potential in Ecuador. The problem of finding sufficient material to mine is encouraged in this case by the width of several hundred metres of more or less mineralized shear zone in the Laguna Negra area. Determination of the grade of mineralization at this site is currently awaiting analysis of samples.

Disseminated pyrite ± chalcopyrite in schists is a relatively common occurrence in the Cordillera Real, notably in association with shear zone-hosted quartz veins, described above. Disseminated sulphides, not obviously related to such veins, were encountered in the Río Collay and Cerro Soroche. These samples have not yet been analysed and their economic significance is presently unknown, however, the known occurrence of (volcanogenic) massive sulphides within the Alao-Paute and Upano subdivision metavolcanic-metasedimentary lithologies (Jemielita, 1991a; Jemielita and Bolaños, 1991), indicates the potential importance of such mineral showings which should be investigated further.

Possible intrusive-related, brittle type (epithermal?) quartz-pyrite veins and associated disseminated and fracture coating pyrite and other sulphides is a common occurrence in black graphitic schists and other metavolcanic and metasedimentary lithologies in the vicinity of the Río Upano-Río Abanico near Macas. This mineralization is thought to be related to intrusion of the Colimbo composite diorite-granodiorite, itself a mineralized intrusion (see below). The extensive, and often intensive, nature of this hydrothermal mineralization constitutes a tremendous potential tonnage of exploitable material but the economic potential of this mineralization awaits assay and analysis of samples. The occurrence of such mineralization in graphitic schists and sediments is encouraging due to the existence of large intrusive-related gold deposits in carbonaceous sediments such as the Carlin gold mine in Nevada, U.S.A.

The Colimbo intrusion was not examined in detail but river boulders from rivers draining this intrusion have abundant examples of diorite and granodiorite with disseminated pyrite, and in some cases chalcopyrite. The lack of porphyritic textures suggest that this is not a porphyry-style of mineralization but, nevertheless, the granular textured intrusion could have potential for disseminated and/or veinlet, bulk tonnage, low grade mineralization. Together with its apparently extensively mineralized aureole, the Colimbo intrusion is an attractive exploration target.

Disseminated pyrite occurs in very extensive, and often intensively mineralized zones in feldspar-phyric dacite-andesite porphyries in the Osogochi-Cerro Soroche and Atillo areas. The largest area of such mineralization occurs at Cerro Pucurcu Grande which, together with potentially similar mineralization at Cerro Pucurcu Chico and other sites near Cerro Soroche and Atillo, constitute huge volumes of mineralized rock. This type of mineralization is associated with phyllic and argillic alteration typical of mineralized porphyry intrusions, some of which have enormous mineral potential. These samples are currently awaiting analysis.

Acid leached, porous silica, porphyry breccia with disseminated pyrite occurs as a concentration of angular blocks exposed by excavations in the bed of the Río Pilares-Quebrada Huagrarumi junction at Collay. Such altered and mineralized breccia has previously been recorded at Gima (Jemielita, 1991b) and is commonly associated with epithermal, porphyry-related, precious metals prospects and deposits. The concentration and angular shape of the Collay samples indicates a very local source and together with the occurrence of felsic volcanic and intrusive rocks and abundant alluvial gold in the area, strongly suggests that this area has considerable economic potential for epithermal precious metals mineralization. Aggressive exploration of this area is strongly recommended.

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Dr. Richard Jemielita

No. 0716

QUITO, MARCH 31, 1992

TO : DIRECTOR GENERAL DE INVESTIGACIÓN GEOLÓGICO-MINERA

FROM : DR. RICHARD JEMIELITA and EGDO. JOHN BOLAÑOS

SUBJECT : Technical Commission Report to: Cochapamba-Oyacachi-El Chaco-Oyacachi River-Santa Maria River-San Juan Grande River-Cosanga-Rivers of the Cosanga area-Coca River-Payamino River-Tena-Rivers of the Tena area-Rivers of the Puyo area-Baños, from February 24 to March 10, 1992.

1. INTRODUCTION

1.1 Project context

The Cordillera Real Geological Project, a technical cooperation between the governments of Ecuador and Great Britain, includes in its third phase the subproject Economic Potential of the Cordillera Real. For this reason, a field mission was carried out from February 24 to March 10, 1992, in order to continue the geological-mineralogical work and studies of the outcrops in the subproject's areas of interest.

1.2 Objective

To continue with the geo-mineralogical research and mining evaluation work in the belt comprising the Cordillera Real of the Andes, in order to determine its future economic potential aimed at national mining development.

1.3 Assigned personnel

To carry out this work, the commission was composed of:

Dr. Richard Jemielita (ODA/BGS)

Egdo. Johnson Bolaños (CODIGEM)

Sr. Cesar Vinueza (CODIGEM)

1.4 Transport

Jeep Land Rover, license plate AT-0274, from the British Mission.

1.5 Detailed activities

Month	Day	Traverse
February	24	Quito-Cangahua-Cochapamba-Cayambe
	25-26	Cayambe-Cochapamba-Oyacachi
	27-28	Ríos Oyacachi area
	29	Oyacachi-Cochapamba-Cayambe
March	01	Cayambe-Papallacta-El Chaco-Baeza
	02	Baeza-El Chaco-Río San Juan Chico-Río San Juan Grande
	03	Río San Juan Grande-Río Santa María
	04	Río Santa María-El Chaco-Baeza
	05-06	Baeza-Cosanga-Río Aliso
	07-08	Río Aliso-Río Cosanga
	09	Río Cosanga-Ríos Area de Tena-Tena
	10	Tena-Ríos Area de Puyo-Puyo-Baños-Quito.

1.6 Access

Some study sections were accessible by vehicle (British Mission Land Rover), such as the El Chico-San Juan section (road under construction), where in certain places four-wheel drive had to be used before continuing on foot. However, in high sections of the Cordillera that generally exceed 3000 meters above sea level, it was necessary to walk and use pack animals to reach the points of interest and thus fulfil the proposed objective; for example, the Cochapamba-Oyacachi section, at the drainage divide, following the trail at the site called “La Montera”, where an altitude of 4000 meters above sea level was recorded.

2. GEOLOGY

2.1 Río Oyacachi (Map 6a)

The Río Oyacachi is a major eastward draining river which cuts across the Andean-trending lithologies of the Cordillera Real. It is the next major river to the north (about 17 km) of the Río Papallacta (Trans-Andean Oil Pipeline route). The area is of interest because of reported gold, copper, lead, zinc and arsenic values from stream sediments in the Río Oyacachi and its tributaries (Arguello and Lamina, 1989), and reported copper mineralization (pyrite, chalcopyrite, bornite) in rock (Píntag 1:100000 geology map) near Cuyuja on the Río Papallacta. In addition, the Río Oyacachi is considered to be gold-bearing (Pillajo and Báez, 1983; Reventador 1:100000 scale geology map).

The area is accessible via a good quality mule track south from Cochapamba along the valley of Q. Pinanhuaycu and across a ridge (altitude 4000 metres) south of Cerro Ambal Sipamba into the upper Río Oyacachi valley. Local topography is steep with páramo vegetation at higher altitudes giving way to scrub and cloud forest in the valleys. When visited the climate was windy, wet and cloudy and the rivers were flooded so the survey was abandoned after three days. Nevertheless, some conclusions may be drawn on the metallogenesis and mineral potential of the area based on previous studies (Litherland, et al., 1990; Arguello and Lamina, 1989).

Country rocks between Cochapamba and Nuevo Oyacachi comprise a thick sequence of purple-pink-cream-white coloured volcanic and volcaniclastic rhyolites to andesites with conspicuous flow banding, vesicles, and porphyritic textures being common. Exposure is rather poor except in cliffs and along roadcuts. Attention should be drawn to numerous mountains in the area with the prefix “Puca”, meaning red in the Quechua Language, and possibly indicating oxidized sulphide mineralization (e.g. Cerro Pucurcu near Osogochi: Jemielita and Bolaños, 1991). In the vicinity of the town of Nuevo Oyacachi greenschist boulders were noted. From this site eastwards Litherland et al. (1990) report the occurrence of metamorphic and plutonic basement lithologies of the Agoyán subdivision, Tres Lagunas subdivision, Chigüinda subdivision, Cerro Hermoso subdivision, Upano subdivision and Azafrán subdivision. Further east, near the junction of the Río Oyacachi and the Río Quijos, Napo and Tena Formation lithologies outcrop. The origin of the gold, copper, lead, zinc and arsenic values from the Río Oyacachi is unknown. Copper mineralization was observed in boulders in the Río Santa María and lower Río Oyacachi (see below) and disseminated copper sulphides have been recorded from basement schists near Cuyuja in the Río Papallacta valley (Píntag 1:100000 scale geological map). Litherland et al. (1990) recorded zinc indications at Oyacachi and blocks of quartz-calcite vein material in graphite schists assaying up to 7593 ppm zinc in the Río Quijos. Furthermore, copper, zinc and lead mineralization is widespread in skarnfield localities in the north (Litherland et al., 1990).

The anomalous base metal values described above may, therefore, be related to mesothermal type quartz veins, disseminated (possibly syngenetic) sulphides in schists, or skarns. The existence of skarns has been postulated in the Oyacachi area (Litherland pers. comme.) but has not been verified to date.

In the lower reaches of the Río Oyacachi, especially in the Ríos Santamaría, San Juan Grande and San Juan Chico, river boulders commonly comprise well-foliated (mylonitized) greenschists, porphyroblastic augen greenschist, finely banded (tuff?) greenschist, and epidotites. The greenschists are commonly cut by veins of massive white metamorphic-type vein quartz often associated with massive white-cream-yellow coloured carbonate (calcite-dolomite-ankerite?), fine-grained, dark green felted masses of chlorite and, occasionally, coarse sulphides (pyrite and chalcopyrite). Other lithologies observed include dark grey coloured, semi-granular schist (sheared porphyry?); dark-grey coloured, fine-grained rock with narrow (centimetre scale) massive, white quartz veins; medium to coarse-grained grey, granular (Tres Lagunas-type) granite with blue quartz grains; maroon-coloured fine-grained mica schist (Tena Formation?); medium-grained, granular granodiorite and granite. The river boulders are dominated by sheared greenschists and indicate proximity to a major ductile fault probably running parallel to the Río Oyacachi (N-S) and mapped as a thrust within the Upano division greenschists (Litherland et al., 1990). Outcrop on the western bank of the Río Oyacachi-Río Santa María, junction was seen to comprise steeply-westward dipping greenschists with narrow (tens of centimetres wide) fabric-parallel quartz veins. It was not possible to examine these rocks in detail due to the flooded condition of the river.

In the Río Santa María, and downstream of its junction with the Río Oyacachi, brown coloured, iron oxide-stained boulders are common. These comprise mostly white-grey-green coloured, fine to medium-grained, sericite-chlorite schist (possibly silicified), with disseminated pyrite and, less commonly, chalcopyrite. These boulders represent sulphide mineralization associated with shearing. The Río Santa María also contains some very large (several metres diameter), medium to coarse-grained granite boulders. The occurrence of copper, zinc, lead, arsenic and gold anomalies, mostly from stream sediments, together with the common occurrence of mineralized (pyrite, chalcopyrite) boulders. In the Río Oyacachi area makes this an attractive target for further detailed exploration.

2.2 Río Cosanga and vicinity (Map 6b)

The Río Cosanga and its tributaries, the ríos Aliso, Yanayacu Grande and Bermejo drain the eastern slopes of the Cordillera Real south-east of the volcano Antisana.

Local topography is very rugged with thick cloud forest vegetation and generally poor access. Climate is warm and humid but at the time of the visit it was wet, cloudy and cold and the rivers were flooded. The Ríos Cosanga, Aliso and Yanayacu grande are classed as auriferous (Pillajo and Báez, 1983) but are not worked for gold according to local information. The Río Cosanga is also classified as having alluvial gold potential on the Baeza (1:100000 scale) geology map.

These rivers drain rocks of the Chigüinda subdivision; Cerro Hermoso subdivision and Upano subdivision in their headwaters near the watershed of the Cordillera Real. They also drain lithologies of the Napo and Tena Formations, as well as serpentinite and Quaternary volcanics in the vicinity of the town of Cosanga.

River boulders in the Río Cosanga, near the town of Cosanga, are dominated by large (< 2 metres diameter), rounded boulders of medium-grained, granular to porphyritic and vesicular, light to dark grey and maroon-coloured volcanics. These lithologies are sometimes flow-banded. Smaller boulders of black, grey and green schists are also common. Black schists are often strongly veined with massive white quartz and some boulders of silicified, sheared and quartz-veined mica schist were noted. Other lithologies seen include medium-grained grey, granular granodiorite and massive, white, metamorphic type vein quartz, the latter often containing inclusions of mica schist and yellow-weathering carbonate (dolomite?). Vein quartz boulders are often iron-oxide stained and one sample was observed containing fine-grained, granular pyrite associated with similarly fine-grained biotite. One boulder of coarse, light to dark green and brown-pink coloured, mottled skarn or serpentinite was observed. Other mineralized samples include a hard, green coloured, massive to poorly foliated rock with disseminated pyrite (skarn? serpentinite?). Chalcopyrite was seen in one massive vein quartz boulder.

Further upstream in the Río Cosanga, above its junction with the Río Aliso, river boulders are dominated by fine to medium-grained, grey, green and black mica schists. Massive, white, metamorphic-type vein quartz is quite common, often forming deformed (centimetre-scale) veins in schists, and larger (tens of cm-scale) discrete boulders. Quartz is often intergrown with coarse-grained white-yellow carbonate, and fine-grained pyrite occurs in some samples. A boulder of iron oxide stained, grey, sericite schist with fine-grained disseminated pyrrhotite and chalcopyrite was sampled (cf. Río Santa María to the north). Boulders of augen schist are quite common. Sediments are represented by black slate and olive brown-green siltstones (Napo Fm. and Tena Fm.), often with narrow interlocking quartz veins. Coarse sieved river gravel was panned at this locality and yielded some black sand for analysis. One or two very small gold colours were observed.

The Río Aliso is a tributary of the Río Cosanga. River boulders were examined in the river about 2 km upstream of its junction with the Cosanga. Lithologies observed in river boulders include massive to banded, medium-grained, porphyritic/vesicular, andesitic volcanics; green, black, and grey mica schists, and one boulder of massive, indurated, green serpentinite. Massive, white, metamorphic type vein quartz is quite common as tension gash veins and deformed veins in schists, and brittle-type interlocking veinlets in black slates (Napo Formation sediments?). Vein quartz is often associated with coarse (dolomite?) carbonate. Fine-grained disseminated pyrite was observed in a boulder of weakly brown iron-oxide stained, silicified, grey mylonite, and also in medium-grained, granular, grey-green, hornblende granodiorite. Sand was panned from the margin of the river but the yield of heavy minerals was poor and no gold was observed.

The Río Yanayacu Grande to the north of the town of Cosanga contains boulders of volcanic lava and breccia; black slates; grey, fine-grained limestone; and grey, green and white schists. Massive white metamorphic-type vein quartz pebbles are quite common. Small pebbles of obsidian were observed, and a boulder of volcanic or intrusive breccia with clasts of black (Napo Formation?) schist or shale was found.

Lithologies observed in the Río Cosanga, Río Aliso and Río Yanayacu Grande confirm the basement lithologies shown on the geological map (Litherland et al., 1990), and indicate a mixed terrain of metamorphic, sedimentary, plutonic and volcanic rocks.

The Río Bermejo is located south of Baeza and is a tributary of the Río Cosanga. The Bermejo is not classed as auriferous (Pillajo and Báez, 1983). Outcrop and river boulders were observed in the river in the vicinity of the Baeza-Cosanga road bridge and upstream of the junction with the Río Cosanga. Outcrop, on both sides of the river at this location, comprises well bedded, steeply west-dipping, maroon coloured, fine-grained mudstone with green coloured reduction spots (Tena Formation?). River boulders comprise large rounded blocks of fragmental volcanics and lavas; black, grey, green and maroon-coloured, fine-grained, mica-schists; medium-grained, granular, green granodiorite with massive white quartz veins; flow banded rhyolite, and fine-grained, massive, cream coloured trachyte.

Mineralized lithologies include strongly brown iron oxide-stained intrusive breccia with clasts of hornblende granodiorite, and similarly iron stained, grey-white biotite-phyric porphyry with disseminated pyrite. Massive white metamorphic-type quartz veins cut black-grey schists and granodiorite. Sometimes these quartz veins contain pyrite.

The presence of massive metamorphic-type vein quartz in most of the rivers described above suggests a possible source for alluvial gold in these rivers but the presence of sulphide-mineralized schists and granodiorites could point to alternative or additional sources.

The occurrence of hydrothermally altered and mineralized porphyries and intrusive breccias in the Río Bermejo indicates volcanic/intrusive related activity with possible potential for base and precious metals mineralization.

2.3 Tena-Río Napo and vicinity (Map 6c)

Rivers were visited mostly to the east of Tena and also the Río Napo in the vicinity of Misahuallí. The area is of interest because of the widespread practice of gold washing (Pillajo and Báez, 1983). Unfortunately, the rivers were flooded at the time of the visit restricting access to the river to observe boulders. In addition, no alluvial miners were working.

The area is fairly accessible along graded roads and tracks. Topography is subdued and vegetation comprises tropical forest. Agricultural land is widespread and the climate is usually warm and humid. Rivers in the area drain the eastern slopes of the Cordillera Real. Lithologies in the catchment area are dominated by granitoids of the Abitagua batholith and Azafrán pluton but other lithologies include Napo and Tena Formation sediments, Upano subdivision metavolcanics and metasediments and, nearer the watershed of the Cordillera Real, calcic-magnetite skarns, Cerro Hermoso subdivision marbles and metasediments, and Agoyán subdivision schists and gneisses (Litherland et al., 1990). Massive, white, metamorphic-type vein quartz pebbles were noted in the Río Tena west of the town of Muyuna.

Rivers in the area are classified as auriferous (Pillajo and Báez, 1983; Villavicencio, 1858), particularly the headwater tributaries of the Río Napo, e.g. Río Pano, Río Tena (Tena 1:100000 scale geology map), Río Verdeyacu (Chalupas 1:100000 scale geology map). Local miners and gold dealers indicated that gold from the Río Napo downstream of Misahuallí was usually rather fine-grained. Samples obtained from dealers at Misahuallí comprise fine to medium-grained flattened plates and discs. The gold is deep yellow in colour and of good quality. Grain surfaces are moderately pitted and sometimes striated. Gold from tributaries upstream is reported to be coarse, but no samples were available for examination.

Bedded gravels of the Tiyuyacu Formation were examined south west of Tena. These comprise poorly lithified beds of purple-brown, coarse quartzitic sands and gravels, dominated by well rounded, well sorted pebbles (centimetre-scale) of massive, white, metamorphic-type vein quartz, as well as grey, microcrystalline quartz and fine-grained grey mica schist. This Formation is classified as auriferous (Pillajo and Báez, 1983), and may be a substantial or at least partial source of the alluvial gold found in active river sediments in the Tena area.

The occurrence of massive metamorphic-type vein quartz as river boulders in the Tena area, as well as comprising pebbles in the Tiyuyacu Formation sediments, suggests that alluvial gold in the Tena area and Río Napo originated from mesothermal shear zone type quartz veins in the Cordillera Real. This type of mineralization has been suggested as a likely source of gold in other parts of the Cordillera Real, e.g. Baños fault (Jemielita, 1991). The Tiyuyacu sediments represent a fairly mature sedimentary environment resulting from a previous erosional episode in the Cordillera Real in Eocene or Oligocene time (Sauer, 1965; Mapa Geológico Nacional de la República del Ecuador DGGM-IGS, 1982). Gold, like the vein quartz pebbles, would be concentrated as a resistate mineral, the former to be released subsequently on erosion of the sediments. The gravels of the Tiyuyacu Formation have lithological and sedimentological similarities to the quartz-tourmaline-gold pebble gravels of the Río Shincata area (Bestión Formation: Pillajo and Báez, 1983; Jemielita, 1991), but are considered to be of different age. Nevertheless, the genetic processes involved in their formation were probably similar.

Alluvial gold in the Tena area and Río Napo is therefore derived likely from at least two sources. Firstly, primary metamorphic-type quartz veins cutting metamorphic and plutonic lithologies of the Cordillera Real and, secondly, gold from the Tiyuyacu (and Tena) Formation, itself previously derived from the former source in Eocene-Oligocene time.

It is interesting to note that the Tiyuyacu Formation also outcrops north of Tena in the headwaters of the Ríos Payamino, Coca and Aguarico, all of which are classified as auriferous (Pillajo and Báez, 1983; Villavicencio, 1858) Tiyuyacu Formation lithologies may contribute alluvial gold to all of these rivers, particularly because the most productive stretches of these rivers lie immediately downstream of the occurrence of Tiyuyacu Formation lithologies (Pillajo and Báez, 1983).

The thickness (70-550 metres; Mapa Geológico Nacional de del Ecuador, DGGM-IGS 1982), widespread occurrence, and nature of the Tiyuyacu Formation makes this an attractive bulk tonnage mineral exploration and should be investigated further.

2.4 Coca-Río Payamino

The town of Coca was visited to investigate the possibilities of obtaining gold samples from the ríos Napo, Payamino and Coca, all of which unite at this location and are classified as auriferous (Pillajo and Báez, 1983). No samples were available at Coca which is dominated by petroleum-related industries. Gold was said to be sold mainly at Tena.

River boulders were examined in the Río Payamino at the ferry crossing to Coca. Boulders (ca. 10 cm scale) comprise rounded, dark to light grey, brown and purple, fine to medium-grained, feldspar-phyric, andesite porphyries. Other less common, lithologies include medium-grained, granular granodiorites, augen granite, obsidian and massive white metamorphic type vein quartz.

The Río Payamino has its headwaters on the eastern slopes of the volcan Sumaco and the river runs eastwards across tuffs, basalts and breccias (Misahuallí Fm.), shales, sandstones and quartzites (Hollín Fm.), black shales and clays, chert, fossiliferous clays and calcareous sands (Napo Fm.) as well as sedimentary lithologies of the Tena, Tiyuyacu, Chalcana, Arajuno and Mera Formations (Mapa Geológico Nacional de la República del Ecuador, 1982 DGGM-IGS). The exclusive occurrence of volcanic and intrusive/metamorphic boulders at the site examined reflects the hardness and preservability of these lithologies in comparison with the lithologies of the sedimentary Formations in the Río Payamino catchment area.

The Río Payamino is of interest because it is worked for alluvial gold but does not have a direct connection with the Cordillera Real. It seems likely that the origin of this gold is the Tiyuyacu Formation and, possibly, other sedimentary Formations (e.g. Tena Formation), previously derived from erosion of the Cordillera Real (Pillajo and Báez, 1983). A volcanic intrusive source or contribution of gold to the metal budget of the Río Payamino cannot be ruled out.

2.5 Río Topo (Map 6d)

The Río Topo is a tributary of the Río Pastaza and is classified as being auriferous (Pillajo and Báez, 1983). The Río Topo flows east then south from the heart of the Llanganates range, draining lithologies of the Tres Lagunas, Agoyán, Cerro Hermoso, Azafrán and Upano subdivisions as well as calcic magnetite skarn (Litherland et al., 1990). River boulders were examined in the vicinity of the Baños-Puyo road bridge immediately upstream of the junction of the Río Topo and the Río Pastaza. The river at this location contains many large (several metres diameter), rounded to angular boulders as well as smaller pebbles and sand. Lithologies encountered include boulders of medium-grained, grey, granular (sometimes sheared) granodiorite; fine-grained, grey, indurated or silicified schist with narrow (centimetre-scale) massive white quartz veins; fine to medium-grained pink porphyritic felsites and granitoids, brown sandstone, and one large boulder of red-green-white (hematite-epidote- quartz) cemented, fine-grained grey rock fragmental breccia. Pebbles comprise fine-grained, grey mica schist; red sandstone; and a range of granite, monzonite, and granodiorite lithologies and massive white metamorphic-type vein quartz. Some angular blocks of fine-grained black rock (Napo Formation?) contain disseminated cubes of pyrite. The steep banks of the Río Topo expose moderately well bedded boulder gravels at this locality. Boulders are well rounded (< 1 metre diameter).

The Río Topo is classified as auriferous (Pillajo and Báez, 1983) and it seems likely that the source of any alluvial gold in the river may be attributed to metamorphic-type quartz veins, mineralization associated with granitoid and/or porphyry intrusions, and possibly skarn mineralization.

3. MINERAL POTENTIAL AND METALLOGENESIS

Mineralization encountered during this field trip may be classified as follows:

i) Mesothermal shear zone hosted quartz (± carbonate ± chlorite ± pyrite ± chalcopyrite ± gold?) veins.

ii) Disseminated sulphides (pyrite-chalcopyrite) in sheared and silicified sericite-chlorite schists.

iii) Disseminated sulphides (pyrite, other?) in skarns and greenschists.

iv) Disseminated sulphides in hydrothermally altered and silicified volcanic porphyries and breccias.

v) Auriferous (vein) quartz-pebble gravel palaeoplacers.

vi) Auriferous placers in recent alluvium.

3.1 Mesothermal shear zone hosted quartz veins

Evidence of mesothermal shear zone hosted quartz veins is common as rounded boulders of massive, white vein quartz in all of the rivers examined (i.e. the Ríos Cosanga-Aliso, Río Tena and the Río Topo). In the Río Oyacachi-Río Santa María and their tributaries vein quartz is commonly associated with coarse cream to yellow-brown weathering carbonate (dolomite-ankerite) and fine-grained green, felted masses of chlorite. Coarse grains of pyrite and rarer chalcopyrite occur. The veins often cut, or contain inclusions of green or grey-black: mica schist, and are often strongly deformed. This type of vein mineralization sometimes carries gold (e.g. California, Mother Lode) and may be responsible for much of the alluvial gold found in the eastward draining rivers of the Cordillera Real between El Chaco in the north and Puyo in the south. This type of mineralization is also relatively common in outcrop. Quartz veins were observed cutting the greenschists of the Upano subdivision at the junction of the Río Oyacachi and the Río Santa María. On the Papallacta-Baeza road about 3 km east of Cuyuja strongly deformed (folded) and boudinaged, concordant and discordant massive, white vein quartz is associated with black biotite crystals and coarse blebs of chalcopyrite (with malachite and limonite), cutting flat lying foliated, grey graphitic schists. Disseminated pyrite, chalcopyrite and bornite have also been recorded cutting mica schists in this vicinity (Mapa Geológico del Ecuador; mapa geológico Píntag escala 1:100000), and may also be related to mesothermal quartz veins. This type of mineralization is relatively common within the sheared lithologies of the Cordillera Real, and is thought to be a likely source for much of the alluvial gold found in Cordilleran rivers.

3.2 Disseminated sulphides in sheared and silicified sericite-chlorite schists

Disseminated sulphides (pyrite, chalcopyrite) in sheared and silicified sericite-chlorite schists are responsible for the occurrence of brown iron-oxide-stained boulders which are common in the lower reaches of the Río Oyacachi and its tributaries, especially in the Río Santa María. These lithologies represent shear related mineralization, possibly associated with mesothermal vein-type mineralization, and may also be auriferous. The common occurrence of mineralized boulders of this type at this locality indicates a nearby and possibly substantially mineralized volume of rock.

3.3 Skarns and greenschists

Disseminated pyrite occurs in skarns and greenschists in the Río Quijos and Río Cosanga and may represent syngenetic or epigenetic (intrusion related) mineralization.

3.4 Porphyries and breccias

Disseminated pyrite occurs in grey-white coloured, hydrothermally altered porphyries and breccias in the Río Bermejo south of Baeza. These lithologies represent volcanic-intrusive related mineralization possibly having gold-silver potential.

3.5 Paleoplacer deposits

Auriferous (vein) quartz pebble gravel palaeoplacer deposits are represented by the Palaeocene-Eocene Tiyuyacu Formation which was examined in the vicinity of Tena. This Formation occurs as an oval shaped exposure on the flanks of an anticlinal structure (Napo uplift) along about 180 km of strike length and located to the east of the Cordillera Real, and as a smaller exposure (ca. 100 km long) in the south-east of Ecuador. The Tiyuyacu Formation is said to be worked for gold in the vicinity of Tena, and has been appraised as a mining target in the vicinity of the Río Aguarico (Barragán, 1984). In addition, the most exploited parts of the auriferous rivers Aguarico, Coca, Payamino, Napo, Curaray, and Cangaime lie immediately downstream of exposures of this Formation.

The pebbles observed in the Tiyuyacu Formation gravels are dominated by massive, white-grey metamorphic-type vein quartz, together with less common fine-grained grey chert and mica schist. It seems likely that gold in these gravels originated from mesothermal quartz veins in the Cordillera Real to the west and became concentrated, together with vein quartz pebbles, as resistate minerals. The Tiyuyacu Formation represents palaeoplacer environment with immense tonnages of potential auriferous material.

3.6 Alluvial gold

Gold is worked in recent sediments in many rivers in the Cordilleran foothills and Oriente, especially the Río Napo. As mentioned above, much of the alluvial gold in rivers in the Oriente probably derives from the Tiyuyacu Formation but this gold, together with alluvial gold in rivers upstream of the Tiyuyacu Formation, was probably ultimately derived from shear zone hosted mesothermal quartz veins located in the basement metamorphic-plutonic lithologies of the Cordillera Real to the west.

From an economic point of view the auriferous Tiyuyacu Formation sediments are considered to be a very attractive bulk-tonnage alluvial gold target. Nevertheless, there may also be potential for hard rock gold and base metal mineralization within the sheared basement lithologies of the Cordillera Real, especially within the greenschists of the Upano subdivision. Exploitation in the latter area is likely to be hampered by the lack of access and rugged terrain.

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Topographic Maps (1:50000 scale): Cangahua, Oyacachi, Santa María de Quijos, Baeza, Papallacta, Cosanga, Tena, Puerto Napo, Río Chalupas, Río Mulatos.

Geology Maps (1:50000 scale): Reventador, Píntag, Baeza, Chalupas, Tena, San José de Poaló, Puerto Napo, Baños, Puyo.

Dr. Richard Jemielita

No. 2137

QUITO, JULY 06, 1992

TO : DIRECTOR GENERAL DE INVESTIGACIÓN GEOLÓGICO-MINERA

FROM : DR. RICHARD JEMIELITA and EGDO. JOHN BOLAÑOS

SUBJECT : Technical report of the commission to Pimampiro-Sigsigpamba-Rio Mataquí-Monte Olivo-Rio San Miguel-Rio Minas-Tuquer-El Cedral-Chamiza-La Bonita-Qda. La Industria-La Sofia-Rio Condué-Rio Cofanes and tributaries, from May 18 to June 06, 1992

1. INTRODUCTION

1.1 Project context

The Cordillera Real geological project, a technical cooperation between the Governments of Ecuador and Great Britain, in its Third Phase includes the Economic Potential of the Cordillera Real subproject. For this reason, the service commission was carried out from May 18 to June 06, 1992, with the aim of continuing the geo-mineralogical work and studies of the outcrops in the areas of interest of the Central Cordillera of the Andes.

1.2 Objective

To continue with the geo-mineralogical research and mining evaluation work in the strip that comprises the Cordillera Real of the Andes to be able to determine its future economic potential aimed at national mining development.

1.3 Assigned personnel

To carry out this work, the commission was composed of:

Dr. Richard Jemielita (ODA/BGS)

Egdo. Johnson Bolaños (CODIGEM)

Sr. José López (CODIGEM)

1.4 Transport

Land Rover Jeep license plate AT-0274 from the British Mission.

1.5 Detailed activities

Month	Day	Traverse
May	18	Quito-Pimampiro-Sigsigpamba-Ibarra (technicians and driver)
	19	Ibarra-Pimampiro-Río Mataquí-Ibarra
	20	Ibarra-Monte Olivo-Río San Miguel-Ibarra
	21	Ibarra-Río Minas (W)-Río Minas (E)-Tulcán
	22	Tulcán-Tuquer-El Cedral-Tulcán
	23	Tulcán-San Gabriel-Chamizo-Río Minas tributaries-Tulcán
	24	Tulcán-La Bonita
	25	La Bonita-Rosa Florida-Qda. La Industria-La Bonita
	26	La Bonita-La Sofía
	27-28	La Sofía-Río Condué area-La Sofía
	29-30	La Sofía-Río Cofanes area-La Sofía
	31	La Sofía-Río Laurel-La Sofía
June	01-02	La Sofía-Qda. Chisparosa area-La Sofía
	03-04	La Sofía-Qda. Guadual area-La Sofía
	05	La Sofía-Río Cofanes-El Remolino-La Sofía
	06	La Sofía-La Bonita-Quito

1.6 Access

The study sections located near the North Pan-American Highway of the country generally have second and third-order motorable roads, such as the areas of Pimampiro, Monte Olivo, La Paz, and Tuquer. In some cases, four-wheel drive had to be used to penetrate further into the Cordillera (over 3500 meters above sea level) and then continue on foot. In the La Bonita sector, the vehicle only reached this town; from there, it was necessary to continue along pack trails toward the locations of La Industria Creek and La Sofia.

2. GEOLOGY

2.1 Pimampiro and vicinity (Map 7a)

Outcrops, mostly in road-cuts, were examined together with river boulders in the Río Mataquí, Río Blanco and Río Verde valleys located south of the town of Pimampiro. These rivers and their tributaries drain the western slopes of the Cordillera Real. Local topography is steep, mostly with open agricultural land and some forest. Páramo vegetation occurs at higher altitudes. Altitudes of the sites examined range between 1800 metres and 2400 metres but the ridge of the Cordillera Real to the east reaches ca. 3800 metres in places. The area is accessible to vehicles along good gravel roads and on foot. The weather was moderate and generally dry.

Local geology comprises an Andean-trending sequence of greenschists, pelitic and semi-pelitic schists. These lithologies are variably sheared and foliated and are intruded in places by a coarse-grained hornblende biotite granodiorite pluton (Pimampiro intrusion) and granitoid dykes. The basement schist lithologies are members of the Agoyán and Monte Olivo subdivisions (Loja Division; Litherland et al., 1990), and granite pegmatites, classified as Tres Lagunas subdivision, are thought to occur in the area. To the east the Condué granite batholith outcrops (Litherland et al., 1990). The basement lithologies are unconformably overlain by andesitic lavas, breccias and agglomerates (Pliocene Angochagua volcanics) and volcanic ash and pyroclastics (Pleistocene Cangahua Formation: Mariano Acosta 1:100000 scale geological sheet). These volcanic lithologies thicken to the west and form spectacular cliff and gorge sections in the river valleys.

River boulder lithologies reflect the basement lithologies in the local area but exotic lithologies, especially granites, are also well represented in the rivers.

The quebrada Yuquin was examined at the road bridge near the town of Ramos Danta (Mariano Acosta 1:50000 topographic sheet). Boulders comprise large (< 1 metre dia.) rounded to sub-angular blocks. Lithologies encountered include medium to coarse-grained, leucocratic, biotite-muscovite granite, sometimes deformed into a granite schist; muscovite and garnet-bearing, semi-pelitic schists; coarse granite pegmatite and, less commonly, greenschist, hornblende diorite, young volcanic lithologies and massive white metamorphic-type vein quartz. Schists commonly display mylonitic fabrics.

The Río Verde was examined at the road bridge immediately south of the town of San Miguel. The course of the river at this location runs parallel to the strong mylonite fabric of the exposed country rock, a colour banded, grey, semi-pelitic schist. The schist fabric trends approximately due north and dips steeply to the west. River boulders (< 5 metre dia., mostly < 2 metres dia.), are well rounded to sub-angular and comprise fine to coarse-grained, medium grey-white, muscovite ± garnet semi-pelitic schists; medium to coarse-grained, leucocratic, biotite-muscovite granite, often cut by narrow veins of aplite and pegmatite; medium-grained, granular granodiorite; coarse-grained granite pegmatite; recent volcanic lithologies; and massive white metamorphic type vein quartz. Less common lithologies encountered include fine to coarse-grained amphibolite and white spotted, porphyroblastic/porphyritic?, green coloured chlorite schists. Augen and mylonite fabrics are common in the schists, and granites sometimes have a weak schist fabric. Pyrite and chalcopyrite were noted as fine disseminated grains in a medium-grained garnet-hornblende rock and also in a fine-grained grey porphyry.

The Río Blanco was examined at the road bridge at San Francisco de Sigsipamba. Boulders (< 5 metres dia.), comprise variably deformed, medium to coarse-grained, muscovite and garnet-bearing, semi-pelitic schists; medium grey, medium to coarse-grained, granular, feldsparphyric granite; recent, purple-grey, andesitic-dacitic, porphyritic lavas and volcaniclastics, sometimes with coarse-grained white, colourless zeolites in vugs; porphyroblastic greenstone; coarse-grained granite pegmatite; and massive white metamorphic-type vein quartz, sometimes intergrown with calcite or dolomite. One boulder of white, medium-grained, granular, quartz-feldspar pegmatite with tourmaline was noted.

Country rock exposed on both sides of the Río Blanco at this location comprises strongly sheared and mylonitized semi-pelitic schist. The foliation trends N22°E and dips 73°W. Steeply plunging Z-folds are sometimes visible and indicate a sub-horizontal dextral sense of shear.

At the east side of the road bridge a dyke of dacite porphyry has intruded the basement schists parallel to the schist fabric.

In general, schist fabrics in the entire area examined lie along an Andean trend. Schist fabrics tend to vary in dip and can be moderately shallow in places. Dips are, however, commonly steep and strongly developed, with mylonitic fabrics indicating strong shearing. Schists fabrics also vary in intensity indicating inhomogeneous strain.

2.2 Mineralization

Mineralization encountered in the area comprises hydrothermally altered granodiorite; massive metamorphic-type quartz veins; brittle, banded quartz-ankerite-sulphide veins; and disseminated pyrite and chalcopyrite seen in river boulders. Previous work noted chromium (fuchsite), lead (galena), and iron (hematite) indications (Litherland and Bermúdez, 1986).

South of Río Mataquí bridge (3 km SE of Pimampiro: Pimampiro 1:50000 scale topographic sheet) variably hydrothermally altered, (possibly an appendage of the Pimampiro pluton) granodiorite is exposed in road cuts for about 500 metres. No sulphides were noted but the intrusion may have some potential for hydrothermal mineralization.

Further south and near the junction of the Ríos Blanco and Pisque a two-metre-thick vein of massive metamorphic-type quartz is exposed within a sequence of grey-black (graphitic) schists. A previous analysis of samples of this vein yielded the following values: 681 ppm Pb, 533 ppm Zn and 11 ppm Ag (Misión Belga, Informe Final, 1988). The schists are pervasively veined by narrower (cm-scale), fabric-parallel quartz veins and veinlets. Quartz veins of the latter type are common within the schist lithologies in the area, and all of the rivers examined contain boulders of massive white vein quartz. In other parts of the Cordillera Real this type of vein mineralization sometimes carries gold but no gold workings were noted either in hard rock or in the rivers in the area.

On the south west side of the Río Blanco valley in road exposure on Loma el Guarango veins (cm to tens of cm thick,) of relatively massive quartz and orange-weathering ankerite, with grains of pyrite and galena, cut a dyke of altered medium-grained (sericite-quartz), granular granitoid. The veins occupy brittle fractures trending ca. N144°E dipping 30° west. A previous analysis of samples of this vein material yielded the following values: 0.4% Pb, 0.14% Zn and 57 ppm Ag (Misión Belga, Informe Final, 1988). Pyrite and chalcopyrite were noted as disseminated grains in a boulder of fine-grained grey porphyry, both from the Río Verde.

In summary, no significant mineralization is known or visible in the area examined and the mineral potential is, accordingly, considered to be low.

2.3 Monte Olivo and vicinity (Map 7a)

The town of Monte Olivo (Pimampiro 1:50000 scale topographic sheet), is located 9 km east of Pimampiro. Local topography is steep and comprises open agricultural land as well as some thick mountain forest. Altitudes in the areas examined range from 2150 metres to 2700 metres. Monte Olivo is accessible to vehicles but all other areas can only be reached on foot.

Local geology is the along-strike equivalent sequence to that encountered in the Pimampiro area (see Pimampiro and vicinity), and is dominated by an Andean-trending sequence of greenschists, semi-pelitic and pelitic schists. The area immediately east of Monte Olivo constitutes the southern end of the tourmaline "pegmatite belt" of Litherland et al. (1990).

Outcrops and road exposures were examined in the area together with river boulders in the Río El Carmen and Río San Miguel. A traverse was made from Monte Olivo, to ca. 3 km to the east, which crosses the pegmatite belt, however, no pegmatites were observed in float or outcrop. Lithologies along the traverse were dominated by muscovite ± garnet semi-pelitic schists, together with sheared granodiorite and fairly common vein quartz. A block of biotite, quartz, feldspar-phyric latite was noted. Outcrop in the Río San Miguel ca. 3 km east of Monte Olivo comprises well banded and foliated medium-grained, grey (sheared) garnet-mica schist with white to green-coloured sericitic alteration in places. Narrow, fabric-parallel quartz veins are common. The schist fabric trends N30°E and dips 58°W, a typical Andean trend. The schist is cut by a 1.5 m thick, sub-vertical, discordant dyke of biotite-muscovite granodiorite. The granodiorite is medium-grained, grey (black-white speckled), and has a poorly developed foliation. Strong brown-yellow iron oxide staining is related to a deformed and discordant, massive, quartz vein containing abundant pyrite and, less common, grains of molybdenite with its characteristic powder-yellow alteration product ferrimolybdite. The vein is partly gossanous and tens of centimetres thick. A possible extension of the vein outcrops on the opposite side of the river.

River boulders are dominated by angular to sub-rounded discs of medium to coarse-grained muscovite-garnet semi-pelitic schists and massive white metamorphic-type vein quartz. Some fine-grained volcanic porphyry was noted. Further downstream and to the south-west of Monte Olivo, on the north bank of the Río San Miguel immediately upstream of its junction with the Quebrada Espejo, river boulders were examined.

River boulders (< 1 metre dia.) are rounded to angular and comprise a range of lithologies including medium to coarse-grained, grey-white banded, muscovite-garnet semi-pelitic schists (sometimes with feldspar megacrysts and, in one instance, needles of black tourmaline; sheared, granular/porphyritic, medium grey coloured, medium to coarse-grained granodiorite; white, medium-grained, muscovite-tourmaline-quartz-feldspathic pegmatite; deformed and undeformed, coarse-grained, black-white speckled diorite and granodiorite, sometimes xenolithic; massive, white metamorphic-type vein quartz, sometimes with pyrite; quartz-feldspar pegmatite (one example with molybdenite another example with chalcopyrite and malachite); orbicular diorite; a granular feldspar rock with coarse pyrite and molybdenite; and a selection of young porphyritic andesite and dacite lavas; deformed porphyroblastic/porphyritic green rock is also present but uncommon.

Country rock at this location comprises a mylonitized, medium-grained, grey, muscovite-garnet, semi-pelitic schist. The schist fabric trends N20°E dipping 60° west, a typical Andean-trend. The basement is overlain by about 60 metres thickness of alluvial terrace conglomerates containing boulders of similar composition to these described above from the active river sediments.

Immediately west of the town of Monte Olivo the Río El Carmen contains boulders of grey, medium to coarse-grained, banded muscovite-garnet semi-pelitic schists and augen schists; fine to coarse-grained, white, quartz-feldspathic pegmatites usually with coarse plates of muscovite and medium-grained black tourmaline needles; greenschist; green-pink banded, and sometimes garnetiferous, amphibolites; green, granular, medium-grained hornblende microdiorite breccia; white, medium-grained, granular, garnetiferous leucogranite with sheared bands; medium to coarse-grained, granular green mafic/ultramafic intrusive rock; a fine-grained green granular rock with prominent euhedral brown coloured crystals; and massive, white-grey, sometimes banded, metamorphic-type vein quartz sometimes with ankerite and often with grains of pyrite and, sometimes, chalcopyrite; and various young porphyritic volcanic lithologies.

About 1 km west of Monte Olivo roadside exposures of pelitic schist give way westwards to greenschists. 2 km west of Monte Olivo a prominent 10-metre-wide exposure of white-yellow-red-brown coloured and hydrothermally altered greenschist forms a visible feature trending ca. N20°E dipping 60°W running down almost the entire height of the north slope of the Río Escudillas valley. The alteration is visible climbing the south slopes of the valley. Alteration is sericitic and kaolinitic with colours due to iron oxides. Texture ranges from foliated to massive. No sulphides were noted but a channel sample was taken for analysis. A previous rock-chip sample from this location yielded the following values: 471 ppm Cu, 79 ppm Pb, 144 ppm Zn and 17 ppm Ag (Misión Belga, Informe Final, 1988). Further west greenschists continue to outcrop along the road to the Quebrada Manzanal where coarse hornblende granodiorite of the Pimampiro pluton is exposed.

2.4 Tuquer-Quebrada Yail (Map 7b)

A brief excursion was made into this area to confirm the existence and location of the so-called "pegmatite belt" of Litherland et al. (1990). The area is generally steep with agricultural land and mountain forest. Altitudes in the areas visited range from 2600 metres to 3300 metres. The area is accessible by road to Tuquer then uphill almost to Alto Tuquer. Further access is only possible on foot.

Local geology comprises basement of muscovite-garnet ± graphite schists and muscovite paragneiss of the Agoyán subdivision, and granite pegmatites of the Tres Lagunas subdivision (Loja division; Litherland et al., 1990). Toward the west young volcanic lithologies lap over the basement rocks.

The area was examined to a point ca. 2.5 km south east of Alto Tuquer along the north east slopes of the Quebrada Yail valley. Exposure is relatively poor, but well-foliated greenschists were encountered, giving way eastwards to grey semi-pelitic schists. The contact between these lithologies occurs ca 1.5 km SE of Alto Tuquer. One boulder of fine to medium-grained, granular, leucocratic quartz-feldspar, muscovite, tourmaline. (Monte Olivo-type) pegmatite was found as a float boulder about 1.5 km SE of Alto Tuquer. No outcrop or extensive float of this pegmatite was located.

No indications of potentially economic mineralization were observed in this area, but narrow, often fabric parallel, veins of massive white metamorphic quartz are relatively common in the basement schists.

The next prominent river to the north east, the Río Pisan, was examined immediately upstream of its junction with the Río Apaqui ca 1.5 km NE of La Gruta de La Paz. Lithologies, represented by river boulders and pebbles, are dominated by recent volcanic and volcaniclastic rocks. Pebbles include discoid, rounded, muscovite-garnet semi-pelitic schists; massive, white, metamorphic-type vein quartz; and, less commonly, medium-grained, foliated, green-white amphibolite and hornblende diorite.

2.5 Chamizo Grande-Quebrada Juan Ibarra-Río Minas.

This area was visited to confirm the existence and extent of the Monte Olivo-type, pegmatite belt and to examine reported alluvial gold occurrences in the area (Litherland and Célleri, 1989; Litherland et al., 1990). The Río Apaqui is known as the Río Minas in this area and, by analogy to other rivers in the Cordillera Real, may be considered to auriferous due to its name.

Topography in the area is moderately steep with a mixture of open agricultural land, mountain forest and páramo at progressively greater altitudes. Altitudes in the areas examined range from 2700 metres to 3200 metres. The weather was variably wet or dry but generally cool. Local geology comprises basement of muscovite-garnet ± graphite schists and muscovite paragneiss of the Agoyán subdivision and granite pegmatites of the Tres Lagunas subdivision (Loja division; Litherland et al., 1990). Towards the west young volcanic lithologies lap on to the basement rocks.

South of Chamizo Grande (San Gabriel 1:50000 scale sheet) the Quebrada Juan Ibarra was examined at two localities. At Chamizo Chico (alt. 2800 m), river boulders comprise mostly grey-white, banded, muscovite ± garnet semi-pelitic schists. Other lithologies include recent volcanic rocks; muscovite-tourmaline-bearing (Monte Olivo-type) pegmatites; and medium-grained hornblende granodiorite. A coarse sieved, stream sediment pan concentrate of relatively abundant black sand yielded no visible gold which had previously been reported from this location (Litherland and Célleri, 1989).

Upstream, the Quebrada Juan Ibarra at the road crossing (alt. 3035 m) is dominated by boulders of medium-grained, grey, well foliated, muscovite ± garnet semi-pelitic schist; porphyritic andesite; and massive metamorphic-type vein quartz. A boulder of muscovite-tourmaline (Monte Olivo-type) pegmatite was noted on the track, but none were seen in the quebrada.

The track was followed south and east along the valley of the Quebrada Atal to the river crossing just north of Loma Nariz del Diablo. Outcrop along the track is poor, but dominated by medium-grained, silver-grey coloured, muscovite (biotite?) garnet semi-pelitic schists. Float boulders in the path also comprise relatively common massive, white metamorphic-type vein quartz and, less commonly, granite pegmatite. Fabric parallel (cm-scale) quartz veins were noted in places within the schists. Lineation fabric within the schists is commonly subhorizontal.

The Quebrada Mueses was examined immediately upstream of its junction with the Río Minas at Chamizo Grande. Boulders comprise semi-pelitic schists; recent volcanic rocks; and some massive, metamorphic-type vein quartz. Coarse sieved stream sediment pan concentrates yielded magnetite and garnet but no visible gold as previously reported (Litherland and Célleri, 1989).

The north bank of the Río Minas was examined at Chamizo Grande, downstream of the road bridge. Boulders (< 2 metres diameter), comprise banded, medium-grained, semi-pelitic schists, and recent volcanic rocks. Massive metamorphic type vein quartz also occurs as discrete boulders and veins in semi-pelitic schists. Sand deposited between the boulders exhibits layers and coatings of black magnetite. A coarse sieved pan concentrate of the sand yielded abundant magnetite and garnet but no visible gold as previously reported (Litherland and Célleri, 1989).

The Río Minas was examined immediately upstream of the road bridge at Portal (San Gabriel 1:50000 scale sheet).

Boulders are dominated by medium-grained, recent volcanic lithologies. Pebbles are dominantly rounded, discoid, medium-grained, grey, semipelitic schist, sometimes with massive quartz veinlets. Other lithologies include grey and green coloured, recent volcanic porphyries. A coarse sieved stream sediment pan concentrate yielded abundant magnetite and garnet but no visible gold was noted.

The Río Minas was examined about 2 km ESE of the town of San Francisco and immediately upstream of its junction with Quebrada Central (Huaca 1:50000 scale sheet).

River boulders are dominated by recent volcanic lithologies and pelitic schists. Stream sediment pan concentrates yielded magnetite and garnet and no visible gold was noted.

Local people were questioned about the Río Minas but claimed to have no knowledge of the origin of the name or any gold workings in the area.

2.6 Pegmatite belt - Summary

The area examined between San Francisco de Sigsipamba (Mariano Acosta 1:50000 scale sheet) to the south, and the Río Minas (Huaca 1:50000 scale sheet) to the north is dominated by semi-pelitic schists of the Agoyán subdivision (Loja division; Litherland et al., 1990), along an Andean-trending strike for about 50 km. These rocks envelope the so-called "pegmatite belt" but field observations indicate that, although the occurrence of muscovite-tourmaline (Monte Olivo-type) pegmatites is relatively widespread, this lithology is not common and was observed only as alluvial/colluvial boulders and never in outcrop. Based upon observation of such boulders in the Río El Carmen at Monte Olivo, it seems likely that the "pegmatites" represent metasomatic alteration and/or anomalously boron and aluminium-rich layers within the Agoyán sub-division semi-pelitic schists. The presence of other (possibly economic) elements within the pegmatites awaits the result of analyses.

2.7 Río Chingual valley to La Bonita

From west to east the road occupies a progressively steeper and deeper (Río Chingual) valley which constitutes the frontier between Ecuador and Colombia. The road varies in altitude from 3150 metres at Cocha Seca to 1980 metres at La Bonita. Land use also changes from agricultural land to thick mountain forest when proceeding east then south.

Outcrops and river boulders were examined at selected localities along the road from Julio Andrade to La Bonita. The road traverses east exposing a section across the Cordillera Real and then south, crossing the Andean-trending lithologies obliquely. From west to east basement lithologies comprise muscovite-garnet ± graphite schists and muscovite paragneisses of the Agoyán subdivision (Loja division; Litherland et al., 1990); deformed granodiorite and diorite porphyry (Azafrán subdivision; and fine biotite and hornblende gneiss of the Santa Bárbara subdivision (Salado division; Litherland et al., 1990). Along the road, and in the west-east section in particular, Quaternary pyroclastic and other volcanic rocks are commonly exposed.

2.5 km ESE of the town of El Carmelo (Tulcán 1:50000 scale topographic sheet), and on the south slope of the Río Pan valley, shallow excavations have exposed black earthy to botryoidal textured manganese oxides (wad) associated with effervescent (CO_2) springs which have a faint sulphurous odour. The occurrence of manganese minerals is small and uneconomical, but other deposits may exist in the area which is composed of Quaternary volcanic rocks.

The Río Minas, to the east of the town of Cocha Seca, was examined. Boulders (< 2 metres diameter) comprise sub-rounded to angular, medium-grained, silver-grey coloured, semi-pelitic schists; maroon to grey coloured, medium-grained, andesite-dacite porphyry volcanics; moderately coarse volcaniclastics, and medium-grained, granular, hornblende granodiorite. Less common lithologies include greenschist and massive white metamorphic-type vein quartz (the latter usually occurring as subconcordant veins in schists). A stream sediment pan concentrate yielded moderately abundant magnetite but no visible gold was noted.

To the east, along the road towards Quebrada Agua Clara, white pumiceous volcanic ash is commonly exposed.

The Quebrada Agua Clara was examined immediately upstream of the road bridge. Boulders and pebbles are dominated by medium-grained, silver-grey coloured, semi-pelitic schists; medium-grained, grey coloured, deformed and undeformed biotite and hornblende granodiorites; massive, dark green coloured amphibolite or metabasite resembling serpentinite; and various recent volcanic and volcaniclastic lithologies. A medium to coarse-grained, mica-rich, deformed, leucocratic pegmatite was also noted.

Further east, steeply-dipping, white pumiceous ash is common in roadcuts but, approaching the Río Soche, basement is exposed and comprises fine to medium-grained, granular/poorly foliated biotite granodiorite schist. River boulders (< 3 m dia.) comprise undeformed and deformed (schistose) diorites and granodiorites. Some massive, white, metamorphic-type vein quartz was noted.

Eastwards to the town of Santa Bárbara roadcuts expose white pumiceous ash and, less commonly, mafic lava. The road then follows the Río Chingual valley south to the town of La Bonita, exposing a sequence of more or less deformed granitoid and semi-pelitic schist lithologies.

At Quebrada El Oso road crossing outcrop on the south bank exposes brown iron-oxide-stained and mylonitized, medium-grained, grey-black coloured biotite schist with fine-grained disseminated pyrite. The schists host veins (tens of cm. thick) of white-grey, massive quartz with fine to coarse-grained blebs and masses of pyrite.

In the area of La Providencia a strongly mylonitized (shear zone) and brown iron oxide-stained exposure of fine-grained, grey coloured mica schist contains disseminated pyrite and a fabric parallel vein (ca. 1 cm wide), of fine-grained, granular pyrite with a pink-coloured alteration envelope. The schist fabric trends approximately N45°E dipping 45°NW and the strong mylonite fabric is exposed for at least tens of metres width across the strike.

Massive, white, metamorphic type quartz veins and veinlets are relatively common within the schist lithologies exposed along this section of the Río Chingual road between Santa Bárbara and La Bonita.

2.8 La Bonita-Rosa Florida (Map 7d)

Rosa Florida is located 7 km south of the town of La Bonita. Local topography is very steep and vegetation is dominated by thick mountain forest. Altitudes in the area traversed range from 1200 m to 2200 m.

Access is only possible by foot or horseback (4½ hours one way) along a sinuous track of very variable quality. Weather varied from cool to warm, dry to very wet.

Local geology comprises deformed granodiorite (La Bonita pluton), and quartz syenite/monzonite (Rosa Florida pluton), of the Abitagua subdivision (Zamora division; Litherland et al., 1990), and deformed continental volcanics of the Misahuallí subdivision (Zamora division).

Lithologies encountered during the traverse south from La Bonita include medium to coarse-grained, poorly deformed to undeformed granodiorite, cut in places by aplite and pegmatite veins; grey, green and beige-coloured schists and, near Rosa Florida, medium to coarse-grained granodiorite.

River boulders were examined in the Quebrada La Industria about 100 metres upstream of the trail bridge.

Country rocks at this locality comprise medium to coarse-grained, xenolithic (angular fine-grained diorite), hornblende granodiorite. Xenoliths (< tens of cm across) are ubiquitous. Narrow fractures or veinlets with pink alteration selvages are common, together with veins of epidote. Fine-grained, disseminated pyrite was also observed.

River boulders (< 5 m across) are usually angular and are dominated by granodiorite as well as very fine-grained, finely banded (millimetre to centimetre scale), hornfelsed, grey-white sediments or tuffs. Colours of the latter lithology vary to shades of green, brown and beige. Disseminated pyrite is concentrated in some sedimentary layers. Other lithologies include epidotized, sub-porphyritic to porphyritic granodiorite; epidotized banded sediments or tuffs; and fine-grained, grey andesite micro-porphyry. Narrow veinlets of white to grey coloured, chalcedonic silica sometimes cut the sediments. Coarse sieved stream sediment yielded a little heavy mineral concentrate but no visible gold was noted.

River boulders in the nearby Río Palmas to the north comprise mostly medium-grained granodiorite and fine-grained, grey, hornfelsed sediment or schist. Banded sediments such as those encountered in the Quebrada -Industria were not seen.

2.9 La Bonita - La Sofía (Map 7d)

The town of La Sofía is located about 16.5 km SE of the town of La Bonita. Local topography is steep and vegetation is dominated by thick mountain forest. Altitudes in the areas traversed and examined range from 1100 metres to 2450 metres. Access is only possible on foot or horseback along a generally well-maintained trail. Weather varied from cool to warm and dry to very wet.

Local geology comprises deformed granodiorite (La Bonita pluton), of the Abitagua subdivision (Zamora division), deformed continental volcanics of the Misahuallí subdivision (Zamora division), and Condué granite of the Azafrán subdivision (Salado division; Litherland et al., 1990).

Lithologies encountered during the traverse from La Bonita to La Sofía include medium to coarse-grained, deformed (sometimes mylonitized to sericite schist), granodiorite; grey and green schists; and massive metamorphic-type vein quartz, sometimes with fine-grained pyrite. Towards La Sofía quebradas draining the mountains to the east contain brown iron oxide-stained boulders of fine-grained, banded sediments. Country rocks in this area are undeformed, medium to coarse-grained granodiorite, cut in places by narrow mafic intrusive dykes and aplite veins.

River boulders and outcrops were examined at several localities:

The Río Cofanes was examined along its east bank downstream of its junction with the Ríos Condué and Laurel. Country rock comprises medium to coarse-grained, grey-white, massive, homogeneous, granular biotite granodiorite. A prominent fracture set trends ca. N107°E dipping 80°N. River boulders (< several metres diameter) are dominated by granodiorite similar to the local outcrop, often containing rounded to angular xenoliths (cm to tens of centimetres across) of grey-green coloured porphyry or schist. A weak schist fabric or flow lineation of crystals and xenoliths is sometimes observed. Another common boulder lithology is fine-grained, grey-white-black coloured, and finely-bedded sediments. Banding ranges from sub-millimetre to metre scale. The sediments comprise alternating quartzite and black mudstone often exhibiting tight folds and boudinaged mudstone layers. These are possibly synsedimentary and/or lithification structures. The sediments are probably turbidites. Narrow (2 to 3 mm across) quartz tension-gash veinlets are commonly seen. The sediments are indurated (hornfelsed?) and commonly occur as irregular, layered, and cavernously weathered boulders. This lithology is often iron oxide stained and contains disseminated pyrite and, possibly, chalcopyrite and pyrrhotite. Other boulder lithologies include a light to medium-grey, indurated or silicified, matrix-supported breccia of volcaniclastic or sedimentary origin. Narrow (< 1 cm across), banded, chalcedony veins were noted cutting this lithology: coarse-grained, granular hornblende granodiorite; medium to coarse-grained, semi-granular, light grey-green schist; and pure white massive calcite within dirty banded calcite (algal or caliche type texture?).

A stream sediment pan concentrate was taken on the east bank of the Río Cofanes immediately downstream of its junction with the Ríos Condué and Laurel. The concentrate contains magnetite, garnet and epidote but no visible gold was noted.

The Quebrada Chisparoza was examined upstream of its junction with the Río Cofanes. River boulders (< 2 metres diameter) comprise medium to coarse-grained, granular and undeformed granodiorite; medium-grained, grey mica schist, sometimes silicified with green epidotic bands; and grey-white banded, fine-grained sediments. Less common lithologies include greenschists (metavolcanics?); fine-grained, white sericite schist; and a range of mylonitic/augen schists, some with porphyritic textures and some with disseminated pyrite. Rare boulders of massive, white, metamorphic-type vein quartz were observed. Epidote is very common in the above lithologies.

Pan concentrates were taken at two localities in the Quebrada Chisparosa. Black magnetite is fairly abundant but no visible gold was noted.

South of La Sofía boulders and outcrops were examined mostly in quebradas and in the Río Cofanes.

At Quebrada Licamancha, boulders and pebbles of medium to coarse-grained, grey, granular biotite, granodiorite were observed, together with fine-grained, grey-silver coloured mica schist with garnets. Massive, white, metamorphic-type vein quartz was also observed. A pan concentrate of stream sediment from the quebrada yielded only black sand and red garnets. No visible gold was noted.

At Quebrada Guagual, country rock comprises spectacularly sheared and interbanded, grey-white, foliated, and medium-grained schist (metagranodiorite), and a fine-grained, dark green coloured, and sometimes porphyritic, meta-basic schist. The banding is repetitive in places and bands range from centimetres to ca. 0.5 metres in width. The shear fabric trends N84°E dipping ca. vertical, a trend perpendicular to the Andean trend, and the shear zone is at least tens of metres wide. In places, massive white metamorphic type vein quartz was observed. River boulders include both sheared and undeformed, medium to coarse-grained, granular, xenolithic granodiorites. Xenoliths are dark grey, rounded to sub-angular, granular and feldspar-phyric. Other lithologies include fine-grained, grey-white banded sediments. The sediments are indurated, and some are brown iron oxide stained with disseminated pyrite visible on fresh surfaces. Epidote is fairly common as vein selvages and fracture coatings. A stream sediment pan concentrate yielded black sand but no visible gold was noted.

On the east bank of the Río Cofanes, just downstream of the Quebrada Guagual confluence, country rock comprises a medium-grained, grey-coloured, sheared granodiorite. Fracture trends are N48°E dipping 32°SE (dominant), and N93°E dipping 75°N. Shear fabric, mineral lineations, and intrusive dikes of basalt follow the latter trend. Stream sediment pan concentrates were taken from depressions formed by the blocky fracture of the country rocks at this locality. The rocks were covered with moss, helping to trap sediment. Pan concentrates contain very abundant magnetite with garnet and epidote. Several grains of visible gold were noted.

On the west bank of the Río Cofanes at this locality river boulders comprise undeformed and, less commonly, deformed granodiorite; grey mica schists; fine-grained, banded, grey-white sediments; some brown iron-oxide-stained greenstone or amphibolite; hornblende pegmatite; and massive, white, metamorphic-type vein quartz. One boulder of grey-pink coloured, medium-grained, poorly foliated muscovite (biotite?) quartzofeldspathic schist with blebs of fine-grained pyrite and, possibly, chalcopyrite, was noted. A pan concentrate of stream sediment from this locality yielded abundant black sand and two grains of visible gold.

Local people claim that gold is panned from the Río Cofanes by up to thirty miners, mostly from sites downstream of the Río Chalares. A small sample of this alluvial gold was obtained and is deep yellow in colour forming fine to medium-grained, irregular to rounded discs, pellets and rods with coarsely pitted surfaces. Nuggets of 30 g weight are said to have been found. One local miner also had samples of sulphide-rich vein material. A sample was obtained consisting of massive white milky quartz and cream coloured dolomite or ankerite, with coarse pyrite, chalcopyrite and sphalerite and a purple-grey, metallic (copper) sulphosalt. Similar material was seen with green, malachite-stained covellite and a dull grey platey metallic mineral possibly chalcocite.

A curious feature of the La Bonita-La Sofía area is the occurrence of both Andean and non-Andean-trending structures. The latter structures represented by foliation, mineral lineations, brittle fractures, vein and dyke orientations, trend between N84°E and N110°E and dip from vertical to 75° north. This orientation has not been previously recognized and should be investigated further.

In summary, the Río Cofanes is worked for alluvial gold. Mineralized river boulders in the La Sofía area comprise sulphide-rich banded and hornfelsed sediments, and schists; sulphide-rich polymetallic vein quartz; and massive metamorphic-type quartz veins. The source of the alluvial gold is not known but may be related to the observed sulphide-mineralized lithologies. The widespread occurrence of indurated/hornfelsed and sulphide mineralized banded sediments in the area, and to the east in the Rosa Florida area, indicates the probable existence of a sedimentary roof pendant above the (La Bonita) granodiorite and located along the intervening ridge. This situation is similar to the geological environment in the Zamora batholith (Litherland et al., 1990) and the area should be investigated for potential skarn-related mineralization.

3. MINERAL POTENTIAL AND METALLOGENESIS

Mineralization encountered during this field trip may be classified as follows:

i) Mesothermal shear zone-hosted quartz (± carbonate ± pyrite ± chalcopyrite ± sphalerite ± sulphosalt ± galena ± molybdenite ± gold?) veins

ii) Disseminated and veinlet pyrite in mylonite.

iii) Disseminated pyrite ± chalcopyrite in a range of rock types including porphyry, granodiorite, schist, garnet-hornblende rock and quartz-feldspar vein or pegmatite.

iv) Disseminated pyrite ± chalcopyrite in epidotized and hornfelsed sedimentary rocks.

v) Earthy black manganese oxide associated with carbonated water springs.

vi) Alluvial gold in active river sediments.

Massive white, metamorphic-type quartz veins and veinlets are quite common within the schist lithologies, dominated by semi-pelitic schists, in the northern part of the Cordillera Real. The quartz veins are sometimes associated with sulphide minerals e.g. in the Monte Olivo area molybdenite occurs in such veins, and in river boulders of similar composition, as well as felsic intrusive lithologies. Molybdenite mineralization has also been reported from the Río Chingual valley (Litherland and Bermúdez, 1986b). The occurrence of molybdenite in the northern part of the Cordillera Real is not surprising given the widespread occurrence of granitoid intrusions and semi-pelitic schists. Nevertheless, no significant indications of potentially economic interest were noted.

Other sulphides associated with massive vein quartz include pyrite, grey copper sulphosalts, sphalerite and galena. Gangue minerals also include dolomite-ankerite carbonates. Vein mineralization of this type often carries precious-metals values but the showings encountered during the present survey are considered insignificant except, perhaps, in the Río Cofanes valley where alluvial gold has been mined traditionally, and where sulphide rich (copper-zinc) vein samples have been observed.

In general, the economic potential of this type of mineralization is considered to be low.

Disseminated and veinlet pyrite was noted in mylonitic schists, especially in the Río Chingual valley. The value of this mineralization awaits analytical results but the economic potential is considered to be low at this stage.

Disseminated pyrite and, less commonly, chalcopyrite is found in a range of rock types including recent volcanic porphyries, granodiorites and diorites, greenschist and semi-pelitic mica schists and, in one example, a garnet-hornblende rock. In most instances these lithologies were encountered as river boulders which would require further exploration to delineate the source and economic potential of these mineral showings.

Disseminated pyrite and chalcopyrite was noted in boulders of hornfelsed sediments in areas south of La Bonita. The geographical occurrence of these boulders is interpreted to indicate the presence of a roof pendant of hornfelsed and mineralized sedimentary rocks, probably located along the ridge between the Ríos Cofanes and Chingual. Samples of the mineralized lithologies have not yet been analysed but there is likely to be significant tonnage potential at the source. The geological environment in this area is similar to that of the mineralized "roof pendant" of the Zamora batholith e.g. Nambija etc., and the presence of alluvial gold in the Río Cofanes and its tributaries is an encouraging indication of the potential for hard rock mineralization. The economic potential of this area is considered to be good.

Alluvial gold is known to be mined from the active sediments of the Río Cofanes but the lack of extensive terraces in the area precludes all but artisanal exploitation.

Manganese mineralization in the Río Pun area is considered to be only in mineralogical curiosity unless larger tonnages of manganiferous material can be located.

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Dr. Richard Jemielita

No. 2903

QUITO, 1992

TO : DIRECTOR GENERAL DE INVESTIGACIÓN GEOLÓGICO-MINERA

FROM : DR. RICHARD JEMIELITA and EGDO. JOHN BOLAÑOS

SUBJECT : Technical report of the commission to the areas of Palora River-Tiririco-Benado River-Sangay River-Llushin River from July 07 to 18

1. INTRODUCTION

1.1 Project context

The Cordillera Real geological project, a technical cooperation between the Governments of Ecuador and Great Britain, in its Third Phase includes the Economic Potential of the Cordillera Real subproject. For this reason, the service commission was carried out from July 07 to 18, 1992, with the aim of continuing the geo-mineralogical work and studies of the outcrops in the areas of interest of the Central Cordillera of the Andes.

1.2 Objective

To continue with the geo-mineralogical research and mining evaluation work in the strip that comprises the Cordillera Real of the Andes to be able to determine its future economic potential aimed at national mining development.

1.3 Assigned personnel

To carry out this work, the commission was composed of:

Dr. Richard Jemielita (ODA/BGS)

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1.4 Transport

Land Rover Jeep license plate AT-0274 from the British Mission.

1.5 Detailed activities

Month	Day	Traverse
	07	
	08	
	09	
	10	
	11	
July	12-13	Río Palora - Río Benado - Río Sangay area
	14	Río Sangay - Río Palora area
	15	Río Palora - Loma Tiririco
	16	Loma Tiririco - Palora
	17	Palora - Río Llushin
	18	Río Llushin - Quito

1.6 Access

It is important to highlight that most of the studied area is accessible only on foot or using pack animals, as is the case for Palora-Tiririco where it was necessary to walk and even travel by canoe to access the Llushín River area. It was not necessary to use four-wheel drive in the vehicle, since it travelled on first and second-order roads, which are regularly maintained.

2. GEOLOGY

2.1 Río Palora (Map 5a)

The area examined constitutes the lower reaches of the Río Palora between its tributaries, the Río Bermejo in the west and the Río Sangay in the east. The area is located about 30 km SW of the town of Palora and is accessible by graded road to El Carmen, then by footpath (log paved) to Tiririco and then by rough forest track to the Río Palora. Altitudes range from 1300 metres to 1900 metres and topography varies from level to very steep. Land use comprises open agricultural land in the east, and steep, thickly forested land in the west.

Local geology comprises Quaternary sediments in the vicinity of Palora, giving way successively westwards to sandstones and shales of the Tena Formation, quartzites of the Hollín Formation, black limestones and shales of the Napo Formation and, finally, andesitic greenstones volcaniclastics and metasediments of the Upano subdivision schists (Salado division; Litherland et al., 1990). Exposure is very poor except along river banks and, occasionally, steep paths.

During the foot traverse from El Carmen to the Río Palora a few exposures of sedimentary breccias or conglomerates were noted. These sediments are fine to medium-grained with a fine-grained clay matrix and tend to be grey-white to red-brown in colour. Westwards, fine-grained, grey-white, well-bedded mudstones or shales were observed and, on the slopes of Tiririco, float of silver-white-green, fine-grained mica schist occurs. From the summit ridge of Tiririco views up the Ríos Sangay and Palora show striking terraces occupying wide valleys. The terraces have been incised by the present river courses which occupy narrower widths.

An encampment was made on the north bank of the Río Palora about 3 km upstream of its junction with the Río Sangay. River boulders and outcrops were examined in the vicinity of the camp and upstream to a point about 1.5 km east (downstream) of the Río Benado. Stream sediments were panned at several localities.

In general, outcrop along the Río Palora comprises maroon-brown coloured, matrix-supported angular fragmental breccia. This lithology often outcrops as vertical canyon walls up to several tens of metres high. In places, exposure comprises a coarse sandstone with rare angular clasts. Clasts are mostly fine to medium-grained, homogeneous volcanic lithologies, and one large block of hornblende porphyry was noted. Weak sub-horizontal clast lineation was observed and a narrow (cm-scale thick), band of fine-grained grey mud was noted. It is felt that the breccia lithology is a lahar or volcanic/sedimentary mudflow deposit.

The lahar is usually overlain by a poorly consolidated, poorly sorted alluvial gravel comprising well rounded boulders in a matrix of pebbles, gravel and coarse sand. This deposit is clast supported and weakly bedded in places. Boulders are dominantly granodiorites, granitoids, and semi-pelitic schists. Some recent volcanic boulders were noted. The alluvium was examined at several localities along the north bank of the Río Palora between its tributaries, the Río Benado in the west, and the Río Sangay in the east. The alluvium is usually two to four metres thick, but may be thicker in places. Gold was panned from the lower layers of the alluvium, especially near the contact with the underlying lahar breccias. The alluvium appears to be quite rich and yielded about 10 colours per pan. Alluvial gold was examined from three locations. The gold- is medium to fine-grained (<3 mm across) and deep yellow in colour. Grains are commonly flattened, rounded, irregular and elongate plates. Surfaces are characterized by fine to medium pitting. The samples examined may not be statistically representative of gold produced during alluvial mining when coarser gold may be recovered. The guide said that the gold was washed from the poorly consolidated alluvium, especially the lower layers, as well as the active river sediments. This section of the Río Palora is the most productive and is said to support about sixty miners at the peak of the mining season. Up to 5 g/day per man of gold was said to be normal production. No miners were working at the time of the visit but alluvial gold operation have previously been observed in the area (Aspden and Saltos, 1989), and the river is classified as being auriferous (Pillajo and Báez, 1983).

The active river sediment in the area comprises well rounded to subangular (< 4 metre diameter) boulders, pebbles, gravel and sand. The boulders comprise a range of lithologies dominated by medium-grained, granular granodiorites; fine to medium-grained, granular to porphyritic, recent andesitic volcanics; medium-grained, grey (semi-pelitic) mica ± garnet schists; fine-grained black-grey coloured, indurated (silicified?) and non-indurated, banded sedimentary rocks (Napo Formation?); fine-grained, grey-black (pelitic) schists; medium to coarse-grained, sheared granitoids; strongly brown iron oxide stained, fine-grained, grey coloured volcanics with disseminated pyrite; and massive white metamorphic-type vein quartz sometimes with fine-grained pyrite in vugs, and often having inclusions of grey or green schists or chlorite. Less common boulder lithologies include fine to medium-grained and sometimes epidotized, greenschists and amphibolites; blue quartz-bearing Tres Lagunas-type granite (see Litherland et al., 1990); and pure white, fine-grained, sericite schist. One boulder of medium to coarse-grained, tourmaline-bearing granite pegmatite was noted. This active alluvial sediment is auriferous.

In summary, the area of the Río Palora examined has a basement of recent (probably Pleistocene-Holocene) volcaniclastic lahar overlain by a veneer of poorly consolidated and auriferous polymictic boulder alluvium. These lithologies appear to fill the wide flat-bottomed (terraced) valleys of the Río Palora and Río Sangay. The terraces have been incised by the Río Palora and its tributaries and the active river alluvium is also auriferous. The lahar basement is likely derived from the active volcano Sangay or, possibly the formerly active volcano El Altar to the south-west and west respectively. The alluvial terrace deposits and active river alluvium are derived from mixed batholithic granitoid, semi-pelitic, pelitic and greenschist metamorphic, and benthic sedimentary-rock sources. The alluvial gold is likely derived from mesothermal shear zone-hosted quartz veins in the batholitic metamorphic hinterland to the west (Cordillera Real).

2.2 Río Llushín (Map 8b)

The Río Llushín is a major eastward-draining river of the Cordillera Real and is located ESE of the-volcano Tungurahua. The upper reaches of the river are extremely inaccessible and the river was only examined between its junction with the Río Pastaza to about 3 km due west. This part of the river is auriferous (Pillajo and Báez, 1983) and is exploited seasonally by artisanal miners. The area is accessible by graded road from the town of Palora to the south bank of the Río Llushín immediately upstream (west) of its junction with the Río Pastaza. Further access west and upstream on the Llushín is by motorized canoe or by footpath. Land use in the area is a mixture of agriculture and thick forest.

Geology comprises a basement of sandstones and conglomerates with quartz pebbles (Arajuno Formation), near the junction of the Río Llushín and the Río Pastaza. About 2 km west of this junction and westwards, red and, purple sandstones, shales and conglomerates of the Tena Formation are exposed (Ecuador 1:1 million geology map 1982; Litherland et al., 1990). Further west and up to the watershed of the Cordillera Real lithologies of the Upano subdivision (greenschists and metasediments) Hollín, Napo and Tena Formations (quartzites; black shales, limestones and minor sandstones; red and purple sandstones, shales and conglomerates respectively), and Azafrán sub-division (mostly plutonic granodiorites-diorites) occur (Litherland et al., 1990).

Andesitic lahar deposits such as those observed in the Río Palora valley (see above) and the Río Llushín valley (see below) have not previously been detailed but may be included within the old alluvial terrace deposits (Pleistocene) shown, for example, flanking the Río Llushín (Baños 1:100000 scale geology map).

At the embarcation point on the south bank of the Río Llushín, outcrop comprises very poorly sorted, purple-brown coloured, matrix supported, angular volcanic fragmental (fragments < 1 metre across) andesitic breccia (lahar). Upstream, and to the west, terrace alluvial deposits are extensively exposed along the river and comprise well rounded boulders (< several metres diameter, mostly< 1 metre diameter) of a massive, homogeneous grey-black coloured rock; grey-black mica schists; granitoids; greenschists, sometimes epidotized; and massive, white, metamorphic-type vein quartz. Recent volcanic lithologies are also represented but are less common. The terrace alluvium is reported to be worked for gold in places but only one locality was visited where a single miner was preparing the site.

About 2 km west of the junction of the Río Llushín and the Río Pastaza the former river runs through a canyon flanked by exposure of maroon coloured, fine-grained sandstone and siltstone, probably belonging to the Cretaceous Tena Formation (Baños, 1:100000 scale geology map). Immediately east of the junction of the Ríos Llushín Grande and Llushín Chico, the maroon-coloured sandstones and siltstones are interbedded or underlain by a relatively coarse, clast-supported, quartz-boulder (< 10s of cm diameter) gravel. The quartz boulders are composed of massive white metamorphic-type vein quartz. The conglomerate is well cemented in places but friable in others and is weakly bedded. In places the cement is composed of a low-density, white-coloured chalcedony, sometimes with slickensides. This matrix could represent postdepositional silicification along faults. Some discrete angular fragments of brown opaline or chalcedonic silica also occur as clasts in the quartz-pebble conglomerate.

A sediment pan concentrate was taken from a friable and matrix supported area within the maroon-coloured silt-quartz pebble conglomerate. Black sand (magnetite) is common along with very fine grains of gold. This type of conglomerate is derived from weathering of a basement terrain with relatively resistant vein quartz, and the latter veins could be the source of gold in the conglomerates. The Tena Formation is classed as auriferous (Pillajo and Báez, 1983).

Playas of active alluvium comprise boulders(<2 metres diameter) to coarse sand composed of fine-grained, homogeneous to porphyritic, sometimes vesicular, grey, red, green and beige-coloured andesitic volcanics; fine to medium-grained grey-coloured rock and semi-pelitic schist often exhibiting brittle-ductile type massive white metamorphic type quartz veins (cm-scale); medium to coarse-grained, granular granodiorites and granites; and brown iron oxide stained, fine-grained, grey-green coloured volcanic rock with disseminated pyrite. In the vicinity of the outcrop of the Tena Formation sediments, maroon to purple coloured silt and sandstones occur as pebbles but these do not seem to survive downstream because of their friable nature. Massive white metamorphic-type vein quartz boulders and pebbles are common and one example was observed containing coarse blebs of chalcopyrite. Characteristic orange-brown weathering ankerite veins and alteration selvages were noted associated with vein quartz in grey-black mica schists and rock.

Alluvial gold was examined from a location about 2 km upstream of the junction of the Río Llushín Grande and the Río Llushín Chico on the latter river. The gold is worked from playas of active alluvial boulder gravel. The gold comprises rather coarse (< 1 cm long) to fine grains. Only a few grains were examined and coarser gold may exist. The grains are deep yellow and have finely pitted surfaces marked by very coarse dents and fractures. The grains are generally equant to elongate and flattened but the larger grains are quite thick. The grains comprise both rounded to irregular nuggets and flat plates. No surface coatings were observed. A silver-coloured amalgamated spot was observed in one grain showing that mercury has been, or is being, used to recover fine gold in the river.

The miners claim that gold is won from both the Río Llushín Grande and Chico but that gold is generally coarser in the former river.

The composition of boulders and pebbles from the playas on the Río Llushín indicate a similarly mixed plutonic-metamorphic-volcanic-sedimentary source to that suggested for the Río Palora (see above). The common presence of massive white metamorphic-type vein quartz is similarly considered to be a likely primary source for the alluvial gold found in the area.

3. MINERAL POTENTIAL AND METALLOGENESIS

Mineralization observed during the survey of the Ríos Palora and Llushín can be classified as follows:

i) Disseminated pyrite in iron oxide-stained boulders of fine-grained volcanic rock.

ii) Pyrite and chalcopyrite as disseminations, masses and veinlets within massive metamorphic-type vein quartz.

iii) Auriferous alluvial boulder conglomerates and gravels, e.g.

a) Vein quartz pebble conglomerates within (Tena Formation) red sandstones and siltstones.

b) Polymict boulder gravels in terraces.

c) Active polymict alluvial boulder gravels.

Strongly brown iron oxide-stained boulders of fine-grained, grey green coloured, homogeneous volcanic lava with disseminated pyrite occur commonly in the active polymict alluvial boulder gravels which comprise the playas of the Río Palora and Río Llushín. The common occurrence of this mineralized lithology indicates a substantial source to the west of the areas visited and, if the samples indicate economic potential (assay), then this source should be investigated.

Massive metamorphic-type vein quartz occurs commonly as discrete boulders and as veins within boulders of other lithologies. The vein quartz sometimes carries pyrite and/or chalcopyrite and is sometimes associated with coarse carbonate and orange-brown coloured ankerite alteration (oxidized). These features are characteristic of mesothermal, shear zone hosted quartz veins, a type of mineralization often associated with gold deposits. This lithology occurs in both the Río Palora and Río Llushín, within the basement sediments (Tena Formation? conglomerates exposed in the Río Llushín), and both the terrace and active alluvial polymict boulder gravels. The occurrence of massive vein quartz together with metamorphic and granitoid lithologies reflects the metamorphic-plutonic nature of the basement exposed to the west in the Cordillera Real and where significant vein mineralization could occur. The extremely inaccessible nature of the source area, together with the difficulty in exploring for vein targets in mountain forest, means that the source veins are of dubious economic potential. This is compounded by much of the area being a designated (Sangay) National Park.

Gold is worked by artisanal miners in the terrace and active alluvial boulder gravels in the Ríos Palora and Llushín and some of their tributaries. The terrace gravels, in particular, could have substantial tonnage potential for an alluvial gold operation but considerable exploration and sampling would be required. It is unlikely that an exploitation license would be granted because much of the area is within a designated national park.

The vein quartz pebble gravels within the red sandstone and siltstone (Tena Formation?) basement sediments of the Río Llushín could have, considerable economic potential if gold grade and tonnage is proven. These gravels are similar in appearance and composition to the auriferous Tiyuyacu Formation (Jemielita and Bolaños, 1992) exposed in the sub-Andean zone along much of the length of the Cordillera Real (Ecuador 1:1 million scale geological map 1982).

In summary, the mineral potential of the area is considered to be good but the economic potential is low or non-existent.

4. REFERENCES

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